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VOLUME 35 FEBRUARY, 1951 NUMBER 1

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SCIENCE EDUCATION

THE OFFICIAL ORGAN OF

The National Association for Research in Science Teaching
The National Council on Elementary Science
The Association of Science Teachers of the Middle States

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Manuscripts and books for review as well as all communications regarding advertising and subscriptions should be sent to the Editor.

SCIENCE EDUCATION: Published in February, March, April, October, and December.

Subscriptions $4.00 a year; foreign, $5.00. Single copies $1.00; $1.25 in foreign countries. Prices on back numbers furnished upon request.

Publication Office: 374 Broadway, Albany, New York.

Entered as second-class matter at the Post Office at Albany, New York, February 13, 1939, under the Act of March 3, 1879.

VOLUME 35 | FEBRUARY, 1951 | NUMBER 1

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(The Contents of SCIENCE EDUCATION are indexed in the Education Index)

SCIENCE EDUCATION

VOLUME 35 FEBRUARY, 1951 NUMBER 1

SOME CONCEPTS BASIC TO AN UNDERSTANDING OF ELECTRICITY AND ELECTRONICS

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TEACHERS in all fields of science are intimately aware of the ceaseless pattern of scientific and technological advance. They recognize it in the task of keeping themselves up to date with the swiftly moving frontier. They come face to face with this new pattern in the form of new materials, or old familiar ones modified, in the courses which they teach. An almost universal effect of this trend is the pressure it exerts on science teachers to "teach more and more in what appears to be less and less time."

In high school science courses, one of the unfortunate outcomes of this pressure is the surrender which scientific *concepts* often make to scientific *applications*. How often do our textbooks present long lists of chemical formulas without considering the principles of valence? How often do we speak to our classes about heredity, about variation, about mutation, without making mention of Mendelian Laws? And how often do our students learn about electric lights without learning about energy transformation? We should look back in retrospect upon today's science teaching, or this week's or this unit's, and ask ourselves—have modern, practical, and genuinely important *applications* of science almost completely crowded a consideration of the *principles* of science from the *teaching-learning* situation? All too often must we plead guilty to this accusation of pedagogical shortcoming.

The condition deplored above is but one extreme of a bi-polar relationship. Many of us, as suggested, neglect principles in favor of applications; many of us err in the opposite direction. There are, of course, many situations in which a consideration of basic concepts is out of place. In some instances, youngsters can understand specific applications in practice while they cannot comprehend the more subtle and abstract aspects of a generalization reduced to a principle. Again, it is frequently an excellent technique to approach the understanding of a concept through a consideration of several practical and familiar applications. In any case, however, we as science teachers must not ignore basic concepts in our science teaching, nor dare we entertain any doubt or uncertainty as to exactly what these concepts are.

Teachers whose scientific background may be remote, or which may never have been adequate, can often find help from statements of basic ideas, logically organized, and tersely stated. The bulk of this paper consists of seventeen such concepts in the field of electricity and electronics.[1] They have been arranged in an order that *could* constitute logical presentation, but need not necessarily do so. They have been checked by experts in the field in an attempt

[1] These concepts originally appeared in a doctoral dissertation entitled *Some Suggestions for Teaching Electronics*, Robert Stollberg, 1947. Copies are on file in the library of Teachers College, Columbia University, New York, New York.

to weed out direct or implied inaccuracies.[2] They have been condensed as much as possible without being reduced to outline form. These seventeen concepts do not constitute an exhaustive list. Experience has shown however, that an understanding of these selected concepts illuminates almost all of what can be taught in the secondary school and much of that involved at college level.

This material is intended as reference material for teachers, not as a course of study for a class of any kind, nor yet as supplementary text material for students. Principles can be learned but poorly, if at all, by exclusive attention to them devoid of their applications in practice. Concepts, like codes of behavior, are not acquired and accepted by treating them as "memory gems." With this warning, then, these seventeen concepts basic to an understanding of electricity and electronics are submitted in the hope that they will help teachers better to help students acquire useful understandings in these aspects of science.

1. *Structure of matter.*—All matter is believed to be composed of a few varieties of basic units, including electrons, protons, and neutrons. These fundamental particles are usually intimately associated with others, thus constituting more complex structures like ions, atoms, and molecules. The 92 known natural elements—as well as the newly produced transuranic elements and the thousand-odd isotopes thus far identified—all owe their respectively unique properties to the number and arrangement of the fundamental particles which constitute their atoms. Compounds, in turn, are composed of molecules, the number of identifiably different kinds of which seems to be without limit. Likewise, their respectively unique properties derive from the number and arrangement of the atoms which constitute them.

The fundamental particles of matter are below the limits of optical vision, no matter how powerfully magnified. Their size, weight, charge, and other physical properties, their behavior, indeed their very existence is known only through indirect methods, involving precise techniques and amazingly ingenious trains of thought.

In many substances, both elements and compounds, there is believed to be a number of "free electrons" which, when acted upon by a suitable force, migrate among the atoms or molecules which compose the substance. All electrons—free and otherwise—bear a unit negative electric charge; when there is a net movement of electrons in any given direction, that flow constitutes an electric current. Substances which possess free electrons, and hence permit a current of electricity,[3] are classified as conductors; those with few or no electrons, which therefore permit no such current, are classified as insulators. Actually, ability to conduct is a matter of degree, and conductors and insulators differ respectively in the extent to which they permit electrons to flow. The best conductors are metals, of which silver has the highest conductivity, although copper and aluminum are the most frequently used. An important exception to this generalization is the element carbon which, while not a metal, is a moderately good conductor.

An historical misfortune and subsequent unrelenting tradition have identified an electric current as a flow of electric charge from positive to negative, as those terms are specified in electrostatics. However, since in most cases (excepting some such as those in the following paragraph) an electric current is identical with a flow of

[2] Virtually all the facts supporting these concepts can be found in standard technical references of physics, electrical engineering, and electronics. No footnotes are made to such information. References included are those to non-textual resources which illustrate or extend the generalization in question.

[3] An electric current is a *flow* of electrons. Common use includes the phrase "flow of current." This is evidently redundant, and hence to be avoided in the interest of good English. In these pages the policy is to use "flow of electrons" or "existence of current," "electric charges move through" or "electric current is in," and similar phrases.

electrons and since electric charges are attracted by their opposites (see concept of electric field), it follows that an electric current is actually a flow of electrons from negative to positive. This more realistic and accurate viewpoint, while of little consequence in a study of "non-electronic electricity," is of tremendous value in a study of electronics (see concept of vacuum tube operation). Fortunately, an increasing number of teachers and textbook writers are abandoning altogether the traditional interpretation, and are without qualification or exception identifying an electric current as having a direction from minus to plus in that portion of the circuit which is external to the electromotive force (see concept of electric circuits).

Under certain conditions electrons travel, projectile-like, through space, in which case they constitute an electric current. This phenomenon is greatly enhanced by evacuation of the space. Again, under certain other conditions, the molecules or atoms which make up a gas or a liquid can be partitioned into two dissimilar parts, known as ions, one bearing a positive and one bearing a negative electric charge. (In many cases, more than two ions are formed, but the algebraic sum of all the positive and negative charges so produced is zero.) Once ionization has occurred, negative ions (which in some cases are electrons) can flow in one direction, and positive ions (which in the case of hydrogen are protons) in the other. These two movements of charged particles each constitute electric currents in the same direction, that is, insofar as the effects of the current are concerned, positive charges moving in one direction are equivalent to negative charges moving in the other.

2. *Electric field.*—Surrounding every electric charge, regardless of polarity and size, there exists an electric field. The field due to any charge is most intense in the immediate vicinity of its source, and extends an infinite distance in all directions. The intensity of the field at any point is inversely proportional to the square of the distance from its course, as well as directly proportional to the magnitude of the electric charge which produces it. This electric field can exist in space; no medium is required. The field can alsc exist in matter, but its pattern is altered according to the kind of substance involved.

The rate of change of the intensity of this field with respect to distance is the potential gradient and is commonly expressed in terms of potential difference per unit distance. The gradient is considered to be increasing in the direction toward a positive charge or away from a negative charge. Charged particles, notably electrons, owe their inter-molecular acceleration to the forces exerted on the particles by the field. Negative particles go up (in the increasing direction of) the potential gradient, and positive ones go down it. Another way of saying this is: the electric field surrounding any charged particle interacts with any other electric field in such a way as to produce a mechanical force of attraction between two dissimilarly charged particles and one of repulsion between two that are similarly charged. The force is directly proportional to the product of the two charges concerned and inversely proportional to the square of the distance between them. This can be expressed mathematically in Coulomb's law thus:

$$f = \frac{Kq_1q_2}{d^2}$$

where f is the force of attraction or repulsion, q_1 and q_2 are the magnitudes of the two charges concerned, d is the distance between them, and k is a constant.

A knowledge of the electric filed and the field potential gradient, together with a few quantitative relationships, enables one to predict the behavior of electrons under most conditions. This concept is extremely valuable in the study of vacuum tube operation and that of electromagnetic radiation.

3. *Relations between electricity and magnetism.*—Electric and magnetic phenomena, long known to be associated with each

other, are actually so closely related as to be almost co-existent. This intimacy may be reduced to this pair of similar sentences:[4]

A changing magnetic field is accompanied by an electric field.

A changing electric field is accompanied by a magnetic field.

The meaning of these may be better comprehended when it is remembered that a current of electricity consists of moving electrons, each accompanied by its own electric field; hence, an electric current is identified with a moving or changing electric field.

This dual relationship is sometimes expressed in greater detail thus:

Associated with every current of electricity is a magnetic field.

Associated with every moving magnet there is an electric field.

An electric charge moving across ("cutting the lines of") a magnetic field has exerted upon it a force perpendicular to the direction of motion (motor principle).

A conductor moving across ("cutting the lines of") a magnetic field has produced in it a potential gradient (generator principle).

This general principle is involved in a great many common and electric phenomena such as electric motors, electric generators, solenoid magnets, transformers, reactors (see section on the concept of inductance), loud speakers, and earphones. Besides assisting the understanding of many electric operations, the concept of the relation between electricity and magnetism is one of the great unifying principles of physics.

4. *Electric circuits.*—When electric components are to be employed for a useful purpose, they are almost always arranged in conductive networks known as circuits. Simple series circuits, parallel circuits, bridge circuits, and other more complex arrangements are examples. Besides the connecting wires, circuits usually contain a source of electric energy, such as a battery of electro-chemical cells, a generator, or a secondary winding of a transformer. In most cases they also include a load for the use of that energy, such as a heating or lighting unit, a motor or other electro-mechanical converter, or perhaps an electro-chemical device. The portion of the network which constitutes the source of electric energy is termed the "internal circuit"; the remainder, consisting of the load, connecting wires, etc., is called the "external circuit." It is important to distinguish between these, since some of the rules of electric polarity are stated in one way for the external circuit, but are reversed for the internal circuit.

In addition, the external circuit may include resistors, capacitors, inductors, vacuum tubes, switches, fuses, and numerous other devices, serving purposes such as separating electric components, limiting current, producing resonant rises in voltage or current (as in the case of series or parallel tuned networks), and numerous other electric functions. Usually the circuit is complete, i.e., there is at least one conductive path for direct current or alternating current or both; it can be traced by starting at one terminal of the source of electric energy, going through the external circuit to the other end, and thence through the internal circuit back to the starting point.

In electronics work, a complex network often constitutes more than one circuit. For example, there may exist in one electric mesh a certain path for direct current, and at the same time a quite different path for alternating current. A selective circuit such as this makes it possible to separate a desirable from an undesirable component, both of which are co-existent in the source. The ability to see a multiplicity of electric circuits in a given network is a valuable asset in understanding the operation of many electronic devices.

5. *Simple mathematical concepts related to electricity.*—Electronics—and the more inclusive field of electricity as well—is a

[4] Einstein, A., and Infeld, L. *The Evolution of Physics,* p. 142. New York: Simon and Schuster, 1942. (Pages 129–148 consist of an elementary discussion of field theory as applied to electricity and magnetism, with considerable emphasis on the development and significance of the theory.)

subject the phenomena of which are amenable to mathematical treatment. Especially when speaking of electric conditions quantitatively, there is no better means of expression than the mathematical one. Even the most complicated electric circuit can be simplified to a few types of components which bear simple mathematical relations to each other. These components include resistance, capacitance, inductance, impedance, potential difference, current, power and others. Mathematical relations among these circuit parameters are exemplified by:

Ohm's law:	$I = E/R$
the power formula:	$P = I^2R$
the reactance formulas:	$X_C = 1/2\pi fC$
and	$X_L = 2\pi fL$
and the resonance formula:	$f_r = 1/2\pi\sqrt{LC}$

in which the algebraic symbol representation is as follows:

- I—current in amperes
- E—electromotive force in volts
- R—resistance in ohms
- P—power in watts
- C—capacitance in farads
- X_C—capacitive reactance in ohms
- L—inductance in henries
- X_L—inductive reactance in ohms
- f—frequency in cycles per second
- f_r—resonant frequency in cycles per second
- π—the ratio between the circumference of a circle and its diameter—i.e., 3.14159.....

It is not here pretended that the only avenue to electronics is a mathematical one, nor that all students find the language of mathematics as meaningful as the more cumbersome but more familiar language of words. On the other hand, there are a few basic relationships in electronics, such as the examples above, which most people can understand in mathematical form and which cannot be so well expressed in any other way. Experience has shown that many beginning students, and all those who go beyond the most elementary levels of understanding, should be exposed to these mathematical representations and given the opportunity to learn to interpret, use, and sometimes formulate them.

The five equations above are chosen as examples because they appear in others of these concepts fundamental to an understanding of electronics.

6. *Ohm's law.*—The foregoing paragraphs have dealt in general terms with the nature of an electric current and with electromotive force, or potential difference.[5] The nature of resistance has been implied. One of the most fundamental quantitative relationships in the field of electronics and that of electricity is that which these three variables bear to each other. Even the best of conductors offer some resistance or

[5] Many persons exercise extreme liberties with terminology in this field. Actually, *electromotive force*, abbreviated emf, refers to a physical property, the work per unit charge, of a source of electric energy. One properly speaks of the electromotive force of an electric cell or generator. *Potential difference*, abbreviated p.d., on the other hand, refers to the work per unit charge necessary to bring electric charge from one point in an electric field—which field may be in an electric circuit—to another point. One properly speaks of the potential difference, or the difference in potential, or the potential drop between two points of an electric field or circuit, or across a portion of a circuit. It should be noted that under no-load conditions the electromotive force of a source is numerically equal to the potential difference between its terminals. Under load conditions, the potential difference across its terminals is less than its electromotive force by an amount equal to the potential drop in the internal circuit.

It is perfectly proper to refer to the potential of one point with respect to another when the potential difference between them is meant. In practice an infinitely distant point, or more often the earth, is used as the reference point. When the reference point is clearly specified, one may properly refer to the *potential* of a point. In electronics work, ground (usually the metal chassis on which the device is constructed) is almost invariably specified as the reference point for potential difference. It is proper in such a context to refer to the *potential* of the plate, for example, when the *potential difference* between plate and ground is really intended.

The term *voltage*, so commonly used, is a relatively improper use of the suffix *age* (other examples in misuse: amperage, wattage, mileage, footage). While the use of *voltage* avoids the necessity of selecting the correct term (electromotive force, potential difference or potential) it also deprives the reader of the niceties of meaning which the proper terms convey.

Unfortunately, tradition has so entrenched certain terms involving voltage into the vocabulary that they can scarcely be deleted at this time. Hence, terms such as voltage divider, voltage amplifier, voltage doubler, voltage regulator, and others seem destined to be permanent verbal fixtures.

"electric friction" to the flow of electrons. This resistance limits the magnitude of current which the electromotive force can produce in a circuit. It is measured in units called *ohms*. An ohm may be defined as that resistance which, when an electromotive force of one volt is applied across it, permits one ampere of current to exist in it.

Ohm's law states this relationship between potential difference, current, and resistance mathematically:

$$I = E/R$$

where I is current in amperes, E is potential difference in volts, and R is resistance in ohms.

This most important relationship has three aspects:

1. Given the electromotive force and the resistance of a circuit, the resultant current can be found thus: $I = E/R$.

2. Given the available current and the required potential difference (or the available electromotive force and the required current) the resistance needed to perform a desired function can be calculated thus: $R = E/I$.

3. Given a resistor and the current in it, the potential drop across the resistor can be computed thus: $E = IR$. In this case the potential of the end of the resistor into which the electrons are flowing is negative with respect to that of the end from which they emerge.

7. *Capacitance.*[6]—An electric capacitor (less properly called a condenser) may consist of two parallel metal plates separated by a non-conductor or by empty space. When connected to opposite terminals of a source of electromotive force, one plate, the positive one, has a dearth of electrons, and the other has an excess of them. When the source of potential difference is removed, the potential difference on the plates remains, hence energy has been stored in the capacitor.

The amount of energy stored in a capacitor depends on the potential difference to which it is charged, and on its ability to receive a charge, i.e., its capacitance (less properly called capacity). This latter feature is a physical property of the capacitor, and increases with increasing plate area, decreases with increasing distance between the plates, and varies with the nature of the non-conductor (the dielectric medium) separating the plates.

Capacitance is measured in units of farads; units of more practical size are micro-farads (μ-farads), and micro-micro-farads ($\mu\mu$-farads), (millionths and trillionths of farads respectively).

When an electromotive force is connected to a capacitor, charge flows, that is, current exists, only while the capacitor plates are acquiring the same potential difference as the source; after that the circuit is effectively open. In an alternating current circuit, however, current may exist most of the time, since the capacitor may charge in one direction, discharge, charge in the opposite direction, discharge again,

[6] Here too there is considerable careless use of terms. The terms *condenser* and *capacity* are no longer in good favor. Strictly acceptable terms may be summarized thus:

Name of device	resistor	capacitor	inductor
Physical property which characterizes device	resistance	capacitance	inductance
Symbol for same	R	C	L
Units in which above property is measured	ohms	farads	henries
Physical property which indicate extent to which device limits current	resistance	capacitive reactance	inductive reactance
Symbol for same	R	X_C	X_L
Units in which above property is measured	ohms	ohms capacitive	ohms inductive

Reactor is a general term applying to either a capacitor or an inductor. Impedance is a general term expressing the degree to which a component or network of components limits current. Resistance, capacitive reactance, and inductive reactance are limiting cases of impedance.

etc., in accordance with the changes in instantaneous electromotive force. The result is that in alternating current circuits, capacitors *appear* to permit a current. Actually, except for leakage, no electrons ever flow through the dielectric medium.

With increased capacitance, more current exists in an alternating current circuit, since more electrons must flow during each alternation to charge the capacitor. Similarly, more current exists in the circuit with increased frequency of alternations, since more charges and discharges of the capacitor occur each second. A capacitor's opposition to electron flow, i.e., its capacitive reactance, depends on its capacitance and on the frequency thus:

$$X_C = 1/2\pi fC$$

where X_C = the capacitive reactance of the capacitor in ohms
f = the frequency of the alternating current in cycles per second.
C = the capacitance of the capacitor in farads

In a purely resistive circuit, the potential difference and the current are "in phase" (i.e., positive peaks of alternating potential difference and current occur simultaneously. In a purely capacitive circuit, the protential difference "lags" the current by 90° (1/4 of a sine wave cycle).

In practice, capacitors may be sheets of metal foil separated by mica, plates of metal separated by air, strips of metal foil separated by waxed or oiled paper and rolled up to save space, or strips of metal foil separated by an electrolytically formed chemical film. Mica and air capacitors are sometimes variable. Electrolytic capacitors are polarized, i.e., positive and negative terminals are not interchangeable.

8. *Inductance.*—A magnetic field surrounds every electric current, even every moving electron. This magnetic field varies in magnitude and direction directly as does the current. Relative motion between a conductor and a magnetic field results in a potential difference being induced in the conductor. This, in turn, produces an electric current if a complete electric circuit exists.

When current exists in a *coil of wire,* the magnetic field formed around one turn links with adjacent turns. If the current and hence the magnetic field are changing, a potential difference is set up in the adjacent turns. This induced electromotive force is such as to oppose the current which produces it. This tendency of a coil of wire to oppose any *change* in current is called inductance and is measured in units of henries. The coil possessing this property is called an inductor.

The inductance of an inductor depends on the number of turns of wire, the size, shape, and spacing of the turns, and the magnetic properties (permeability) of the adjacent space, particularly the core (inside the coil). When high inductance is desired, many turns are used, and the core is made of soft (highly permeable) iron.

Since an inductor opposes *changes* in current, it presents opposition, or reactance least of all to direct current (in fact, only to the growth or decay of direct current), most of all to high frequency alternating current. This relationship can be expressed thus:

$$X_L = 2\pi fL$$

where X_L = inductive reactance in ohms
f = frequency in cycles per second
L = inductance in henries

In a purely inductive circuit, the current lags the potential difference by 90° (1/4 of a sine wave cycle). It will be noted that this is precisely the opposite of the situation in a purely capacitive circuit.

If two coils of wire are in close proximity, variations of current in one, usually called the primary winding, induce an emf in the other, or secondary winding. This phenomenon is known as *mutual inductance,* and devices which employ it are *transformers.* If the secondary circuit is complete, the induced emf produces a current. It should be noted that only *changes* in primary current produce secondary emf. Direct current, as long as it remains constant, has no effect on the secondary; fluc-

tuating direct current in the primary produces alternating emf in the secondary. Ignoring losses due to distributed resistance and capacitance, the nature of fluctuations of current and potential difference in the primary and of those in the secondary are all identical; the ratio of the potential differences in primary and secondary is equal to the ratio of primary turns to secondary turns.

9. *Electric resonance.*—Many electric networks offer difference impedances to potential differences of different frequencies. Such circuits are said to be non-ohmic, or selective to frequency. Series and parallel resonant circuits are two simple examples of such networks. Each contains both capacitance and inductance, connected in series or parallel, as the case may be (and no circuit can be without some resistance).

In the former case, the two reactors are in series with the applied potential difference. The electric behavior may be outlined thus:

Impedance—minimum at resonance
Current in the network—maximum at resonance
Potential difference across each reactor—maximum at resonance (resonant rise of potential difference)

In the latter case, the two reactors are in parallel with the applied potential difference, and the electric behavior may be outlined thus:

Impedance—maximum at resonance
Current in the combined network—minimum at resonance
Current in each reactor—maximum at resonance (resonant rise of current)

From the above it is seen that, whereas the series resonant circuit tends to *permit* current consisting of frequencies to which it is resonant, the parallel resonant circuit tends to *reject* current consisting of those to which it is resonant. For both types of circuits the resonant frequency is given by the formula:

$$f_r = 1/2\pi\sqrt{LC}$$

This shows the frequency to which the circuit is most selective, i.e., in the series case, the frequency to which it offers the smallest impedance, and in the parallel case, the one to which it offers the greatest impedance. It will be noted that neither circuit selects one and only one frequency. Actually, a *band* of frequencies is selected, the width of the band being variable within limits, and subject to the control of the circuit designer.

The operation of an electrically resonant system containing inductance, capacitance, and resistance is closely analogous (in the better sense of the word) to a mechanically resonant system possessing inertia, elasticity, and friction, respectively. An example of the latter is a vibrating string, as in a piano or a violin. In both the electric and mechanical cases, the resonant system may be referred to as being *tuned* to a certain frequency (the resonant frequency), and the network itself may be called a tuned circuit or system.

In electronics, resonant circuits find frequent application wherever it is desired to accept or reject a given band of frequencies. In tuning a radio receiver, for example, the band of frequencies to be accepted by the device is determined by the setting of one or more resonant circuits, which may be of the series or parallel variety, depending on the design of the device.

10. *Symbols.*—Almost all of the constituent parts used in electronics are represented by standard symbols on paper or blackboard. When arranged into a meaningful network, the pattern of symbols so produced is called a *schematic diagram.* The character of the individual symbols and the manner in which they are assembled to form schematic diagrams have been fairly well systematized throughout educational and industrial electronics. It is important that students learn the association between symbols and physical parts, so that they can transfer readily from representation to entity or vice versa.

The use of symbols is more than a mere association, however. To the seasoned technician the symbols become a genuinely operational representation. The symbol

for a resistor, for example, is much more general in scope than any illustration or description of a resistor could possibly be. In this respect, the symbol as a representation is superior even to the visual image of the component part, since the latter varies widely from one variety of resistor to another.

Actually, when one who is proficient in practical electronics looks at an array of parts, such as the underside of a receiver, he thinks not in terms of round resistors, black tubes, irregularly shaped transformers, and twisted wires, but rather in terms of conventional symbols. Furthermore, their spatial arrangement in his "mind's eye" does not correspond to that of the physical parts on the chassis, but rather to their conventional configuration in a schematic diagram.

11. *Relations between direct current and alternating current.*—In the simplest cases, electromotive force or potential difference exists in a fixed magnitude and direction. The sources are usually either electrochemical devices, such as cells, or electromechanical devices, such as generators. Electric systems involving such sources are called direct current systems, abbreviated d.c.

On the other hand, some electric generators develop an electromotive force which, far from being constant, varies with time both in amplitude and in polarity. The relationship between amplitude (polarity may be considered the algebraic sign of amplitude) and time is that of the familiar sine function from trigonometry. Such an electromotive force (or the current resulting therefrom) is said to be *sinusoidal*. Electric systems characterized by such energy sources are called alternating current systems, abbreviated a.c.

Electric energy as supplied by utilities companies is commonly delivered in one of these two forms. Each system has some advantages, some disadvantages. For example:

D.C. is of value in electro-chemical processes, such as electro-plating and electrolytic recovery of metals from their ores (aluminum, for example). A.C. is not.

Electric motors operating on d.c. are much easier to control and to regulate than those operating on a.c. Hence the former are, from that point of view, more desirable for electric elevators, electric railways, etc.

D.C. is essential for satisfactory operation of arc lights.

On the other hand:

A.C. may have its potential differences increased and its current decreased, or vice versa, through the use of a transformer.

Because a transformer system permits high potential difference and low current for transmission of power over great distances, line losses may be reduced in a.c. systems (line loss is a function of current).

Switches carrying high current in a.c. systems present only minor difficulties due to arcing.

Many electric appliances designed for use on d.c. will not operate on a.c. On the other hand, some radios, heating units, and motors designed for use with a.c. will be seriously damaged if used on d.c.

It is possible to convert energy from either of these forms into the other by any one of several means. (See the concept of rectification of alternating current). Increased skill and improved technics along these lines are reducing the seriousness of the disadvantages of a.c. systems as compared to those using d.c., with the resulting ascendancy of the former.

12. *Rectification of alternating current.*—So important is the electronic conversion of alternating current to direct current that it is worthy of independent consideration on these pages. Likewise in textbooks or courses of study in electronics, it is commonly given special attention.

Until electronic means became practical, the only means of converting a.c. into d.c. on a truly large scale was to supply a.c. motors to drive d.c. generators. This naturally involves expensive equipment, constant attention to moving parts, and uneconomically low efficiency. True, for low current loads, such as battery charging, there were gas rectifiers, electrolytic systems, and copper-copper oxide type chemical rectifiers. By and large, however, conversion of a.c. to d.c. was a difficult

problem, one to be avoided wherever possible.

With the advent of high capacity thermionic rectifiers, however, this inconvenient circumvention has become unnecessary; banks of electronic rectifiers can supply d.c. from a.c. power lines in literally any desired amount. Furthermore, ingenious grid controls in the rectifiers themselves make possible the control *at the point of rectification* of the d.c. energy delivered. Systems such as these usually involve thyratrons or other types of gas-filled tubes. They make possible an accurate, convenient, and economical control of d.c. motors from a.c. sources.

Of special concern to the household radio user is the fact that electronic amplifiers require a well-filtered source (i.e., one without appreciable a.c. components) of d.c. for their operation. Modern, efficient, electronic rectifier systems have eliminated from the household scene the once-familiar rack of chemical cells for radio operation.

The principle underlying the operation of electronic rectifiers is that a two-element vacuum tube, or valve, as the British so aptly call it, permits current in one direction only. This is because only one element, called the cathode, is heated; therefore only it emits electrons, and the tube permits current only from the cathode to the other element, called the anode or plate. The resulting current, though unidirectional, is intermittent or at least fluctuating. This "ripple" can be eliminated by the use of properly designed filter systems.

13. *Vacuum tube operation.*—In addition to the simple two-electrode vacuum tube, or diode, mentioned under the previous heading, there are numerous other more complex families of electron tubes, some having greatly increased numbers of electrodes. The theory of operation of a triode is typical and informative, and is briefly considered here.

As in a diode, the potential gradient which causes electron flow is provided by a positive (with respect to ground) potential to which the plate of the tube is connected. The negative terminal of this energy supply is returned directly or indirectly to the cathode. The positive terminal of this source of electromotive force is commonly referred to as "B plus," the negative terminal as "B minus" or more commonly "ground."

In addition to the cathode and the plate, the triode contains a third element, located between the other two. This is the control grid, or more simply, the grid. It is a helix or lattice-work of fine wires, and in itself offers practically no obstruction to the flow of electrons.

An electric charge on the grid exercises control over the number of electrons traveling from cathode to plate, i.e., it governs the magnitude of the space current in the tube. Control occurs as a result of the electric potential condition of the grid with respect to the local source of electrons, the cathode; the more negative this potential with respect to the cathode, the fewer electrons flow, and vice versa.

The variation in tube current, or plate current, can be reconverted into variation of potential difference by placing resistance in the plate circuit. In this resistance-coupled amplifier, the varying current is co-existent with a correspondingly varying potential difference across the resistor (*per* Ohm's Law, $E = IR$. The magnitude of this fluctuation may be many times that which controls it. Thus amplification has been effected, since a small change of grid-cathode potential difference controls a larger fluctuation of potential difference at the output of the tube.

In another type of amplifier circuit, the plate of the vacuum tube is connected directly to the primary winding of a transformer. The fluctuating direct current in the primary produces a correspondingly fluctuating alternating emf (and sometimes also a current) in the secondary, thus constituting a stage of transformer-coupled amplification. It should be noted that in

either of these amplifier circuits, the actual energy at the tube input, the grid, never arrives at the output, or plate circuit. Rather, it controls another supply of energy, a source local to the plate in question. Any mention of amplification of voltage or power should be made with this qualifying interpretation in mind.

Another significant feature is that the control at the input of the stage involves practically no current, and hence negligible power. Furthermore, the action of the grid-cathode potential difference on the electron stream occurs almost instantaneously, and results in a control effect of micrometric proportions. These features account for the unique and immensely valuable properties of electronic systems: *they permit virtually energyless signals to control large quantities of energy with amazing speed, accuracy, and flexibility.*

14. *Signal.*—A genuine understanding of the significance of a signal in electronics is at the same time extremely important and difficult to attain. As the word is used in electronics, a signal might be described as *intelligence in transit.* Here the word "intelligence" is used in a special sense. It might be a pure sine wave of a given frequency or an intermittent tone, as in radio code; it might be a single increase in potential difference as in the case of an electronic motor control, or a few micro-seconds' pulse of ultra-high frequency radiation, as in the case of a radar "echo"; it might be a sound wave representing the human voice, the wave form of which can be reduced to a combination of many different sine waves of assorted and verying frequencies and amplitudes, or it might be a potential difference whose fluctuations correspond to a voice, superimposed or modulated upon a sinusoidal radio-frequency carrier wave. All signals of human origin convey some sort of a fluctuation which reflects the will of the originator.

The constitution of a signal may be as varied as its contents. It may consist of fluctuations in potential difference, current, power, pressure, distance, force, velocity, temperature, radiation, or almost any other physical dependent variable. A signal may be transformed from any form, directly or indirectly, to any other form. Examples are:

From sound energy to electric energy as in a microphone.

From electric energy to radiation energy as in a transmitting antenna.

From mechanical motion to electric energy as in a phonograph pick-up unit.

Despite changes in form, and assuming faithful reproduction, the intelligence of the signal remains unchanged.

A signal might be thought of as a change, with respect to time, of a physical quantity, which can produce and/or control an exactly corresponding change in some other physical quantity. References to signal amplification should be made with the same reservations as those mentioned in connection with voltage or power amplification.

Most applications of electronics are arrangements of electric and mechanical components so designed as to permit the controlled transformation, amplification, and/or direction of some desirable signal or set of signals. Many electronic designs can be best understood through an understanding of the concept of signal, and defects in electronic appliances may often be found by locating the point at which the signal path is interrupted.

It is difficult for anyone to acquire any significant understanding of modern electronics or an appreciation of its performance without a thorough and meaningful concept of signal.

15. *Electromagnetic radiation.*—The awareness that electric fields and magnetic fields are intimately and inseparably associated with each other led scientists to propound the theory of electromagnetic propagation of various forms of radiant energy.[7] Examples of these forms of radiation are radio waves, heat waves, infra-red "light,"

[7] Einstein, A., and Infeld, L., *op. cit.*, pp. 148–160, includes an excellent account of the development of this concept from earlier ideas.

visible light, ultraviolet "light," x-rays, and cosmic rays, in ascending order of frequency. The wave structure does not satisfactorily explain all radiation phenomena: for example, the photoelectric effect. On the other hand, the quantum theory of energy radiation, while it explains the photoelectric effect very satisfactorily, fails in regard to phenomena related to diffraction, with which the electromagnetic structure is in complete accord.[8] Faced with this dilemma, physicists, while still seeking a universally acceptable explanation, feel free to employ that theory of radiation which most satisfactorily explains the phenomena at hand, and the extension of which provides fruitful predictions. In the case of a radio wave propagated through space, this distinction clearly falls to the electromagnetic theory, and students of radio employ it almost exclusively in their explanations and design.

Accordingly, radiant energy is described as two co-existent fields, one electric and one magnetic, mutually perpendicular and also perpendicular to the direction of propagation. The intensity of each of these vectors is fluctuating sinusoidally at a frequency identified as that of the wave itself. The band of broadcast radio transmission, for example, involves frequencies from 540,000 cycles per second to 1,600,000 cycles per second. Modern ultra-high frequency technics extend to frequencies as high as 60,000,000,000 cycles per second. Electromagnetic waves of radio-frequency can be generated either by an alternating electric field or by an alternating magnetic field, the frequency of which is equal to that of the desired radiation. Like all radiant energy, radio waves travel through empty space at a velocity of 186,000 miles per second, and in ordinary atmosphere at velocities only slightly smaller. Whenever an electromagnetic wave impinges upon a conductor, a potential gradient is induced. This can be considered as another example of the generator principle. The antenna of a receiver constitutes such a conductor. The induced potential gradient being in the order of micro-volts per meter, it must be greatly amplified before it can be put to whatever purpose is intended for it by the designer.

Under most circumstances, electro-magnetic radiation travels in straight lines. A common exception is the change of direction of propagation when radiation passes from a medium of a certain "radiation density" (dielectric constant) to one of another. As in the familiar example of visible light, this phenomenon is known as refraction. Also as in the case of light, when the boundary between the two mediums is abrupt, reflection also occurs. When electro-magnetic radiation strikes a medium which is, relative to air or space, a good conductor of electricity, this reflection is very prominent, and refraction is virtually non-existent. When high frequency radio waves strike the ionosphere, they reflect in this fashion—likewise when they strike the earth; in this way such energy frequently "bounces" between the ionosphere and the earth, thus covering ranges far in excess of the line-of-sight distance.

The fact that electro-magnetic waves are reflected from metal objects, and—to a lesser extent—from earth and water, coupled with man's ability to measure the time elapsed between an outgoing pulse of energy and its reflected "echo," makes possible the recent advent of navigational and military devices known as radar (*RA*dio *D*etection *A*nd *R*anging).

16. *Nature of sound.*—Sound is clearly a non-electronic phenomenon. However, radio communication, which constitutes an extremely important application of electronics, is very closely allied with sound. It will be remembered that it is one of the forms from which or to which a signal may be transformed. It is for these reasons that a consideration of the nature of sound is in order in this discussion.

Sound is one aspect of physics which can be well understood from the point of view

[8] *Ibid.*, pp. 272–280, presents a typical viewpoint on this paradoxical situation.

of classical mechanics, and without reference to field theory, relativity, etc. While radiant energy is also a wave phenomenon its nature is distinctly different from that of sound. Whereas, in the former case, the direction of the disturbance is perpendicular to the direction of propagation, in the case of sound the disturbance is parallel with the direction of propagation. The former is an example of transverse wave motion while the latter is one of longitudinal wave motion.

In sound, the disturbance consists of displacement of the molecules of the conducting medium. Regions where the molecules are temporarily crowded together are called compressions, while those where they are temporarily dispersed are called rarefactions. As a sound wave passes a particular point, a given molecule is alternately in regions of compression and rarefaction. This does not mean that the molecules move from region to region; they are confined to oscillatory motion limited usually to a very small fraction of an inch. Rather, the successive regions of compression and rarefaction constituting the sound wave itself move through the medium. From this it is quite evident that sound cannot be transmitted through evacuated space. Sound waves can be produced by any mechanically vibrating surface, animate or otherwise.

In air at normal conditions of temperature and pressure, the speed of a sound wave is roughly 1,100 feet per second; in water and in solids it is several times as great. With increasing frequency the propagation of sound becomes quite directional, and the familiar phenomenon of sound being transmitted freely around all corners and obstructions is no longer observed. This effect is noticeable beginning at about 5,000 cycles per second.

Sound waves impinging on flexible objects set them into vibration. When the tympanic membrane, auditory ossicles, and cochlear fluid of a living ear are thus set into motion, the impulse is registered upon the nerve endings and sensed by the animal's brain as sound. Normal human beings can seldom hear sounds above 20,000 cycles per second, and those below about 16 cycles per second, if heard at all, sound more like noise than like musical notes. The sensitivity of the human ear to sound waves varies widely with frequency, i.e., sounds with the same energy content but of different frequency do not sound equally loud. Furthermore, the frequency response of the human ear deteriorates significantly with age, falling off at the higher frequencies with advancing age.

Though inaudible, sound does exist at frequencies much higher than 20,000 cycles per second. This is referred to as the super-sonic, or ultra-sonic, range. Sonar (*SO*und *N*avigation *A*nd *R*anging), an important submarine detection device developed during the recent war, makes use of water-conducted signals in this region. One might describe it as a "super-sonic echo detector."

A musical tone has properties of pitch, depending primarily on frequency; loudness, depending primarily on amplitude; and quality or timbre, depending primarily on the number and proportions of harmonics or overtones. These properties would seem to be independent of each other, and are often considered to be so. But subjectively, that is so far as the listener's brain is concerned, they are noticeably interdependent.[9] Other less frequently recognized characteristics of musical tones are duration, growth and decay time pattern, and vibratto.

A concept of the nature of sound, not only from the physical but also from the psychological point of view, is a valuable asset in studying those portions of electronics which have to do with the electrical or electromagnetic transmission of signals originating in the form of sound.

[9] Fletcher, H. "The Pitch, Loudness, and Quality of Musical Tones," *American Journal of Physics*, 14:215–225, July–August, 1946—treats this little known inter-relationship in convincing detail.

17. *Fidelity of reproduction of sound.*—Like that of the nature of sound, this concept is also non-electronic. However, it is included herewith for much the same reasons as mentioned in the preceding section.

In communications electronics, particularly in the case of reproduction of music, one is frequently concerned with the faithfulness or the fidelity of the sound reproduced. The extent to which a reproduced sound deviates from the original sound can be analyzed in terms of:

Wave-forms or harmonic distortion—the contour of the output signal differs from that of the input signal.

Frequency distortion or discrimination—signals of different frequency but identical amplitudes are not reproduced with identical amplitudes.

Phase distortion—the phase relationships (coincidence of compressions, for example) of two different components of the original signal is not the same in the output as it was in the input.

Cross-modulation distortion—the interaction of two co-existent components of the input signal, introduces spurious and undesirable components in the output.

And some others.

As a rule, none but the highly trained ear can detect wave-form distortion in quantities less than about 5 per cent of the total. Many inexpensive receivers and amplifiers reproduce sounds containing wave-form distortion in quantities as much as 25 per cent or even more. Frequency distortion, on the other hand, is often deliberately introduced by the listeners, as when they boost the bass—or less often the treble—output of a reproducer. Actually, if an otherwise faithful reproducer has a frequency resonance so poor that notes between the limited range of 60 cycles per second and 8,000 cycles per second are amplified uniformly plus or minus an energy factor of two, the output is so unusually pleasing as to make most listeners glow with satisfaction. Phase distortion is relatively unimportant, since it may be present in quite large quantities without causing displeasure to the listener. Cross-modulation distortion is an extremely involved form of infidelity, requiring special equipment to detect and measure, and requiring an unusually well-trained ear to identify.

Distortion may be introduced by inadequate components, particularly in the electronic portions of the amplifier, or faulty design of the system itself. A borderline case of distortion is involved when speech or music is reproduced at amplitudes other than that at which it originated. An important consideration in fidelity is the acoustic nature of the room in which the sound signal is originated and also of that in which it is reproduced. Strictly speaking, absolute fidelity exists only when:

The acoustic properties of the originating and the reproducing rooms are identical.

The amplitude of the reproduced signal is identical with that of the original.

The source of the *reproduced* sound is distributed in space in the same pattern as the source of the *original* sound.

No wave-form, frequency, phase, cross-modulation, or other form of distortion has been introduced by the reproducing system.

Most commercial reproducers introduce an unnecessary but tolerable amount of distortion. Most listeners, who all too infrequently—if ever—have the opportunity to listen to high quality reproduction, willingly endure what they hear. While absolute fidelity of reproduction cannot be realized except under laboratory conditions, it can be sufficiently closely approached, even at moderate cost, to make the discerning listener reject the typical commercial reproducer in disgust.

A meaningful concept of fidelity and how it may be obtained is a valuable asset to the student of communications electronics, and a source of satisfaction and appreciation to the listener, technical or otherwise.[10]

[10] *Frequency Range and Power Considerations in Music Reproduction,* Technical Monograph No. 3. Jensen Radio Manufacturing Company, Chicago, Illinois. An excellent treatise, brief and elementary, on subjects related to high fidelity reproduction of sound.

"Music in the Home," *Fortune,* 34:156 ff., October, 1946. Another treatment, somewhat less technical, in the same general field.

SCIENTIFIC INQUIRY FOR SCIENCE TEACHERS[1]

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THE terms "scientific attitudes" and "scientific method" have been prominent in many statements of educational objectives. Because the ideas to which these terms refer are important, some meanings of the terms have been examined and a detailed summary of the ideas referred to by such terms has been prepared.

ON TERMINOLOGY

Definition of "Scientific Method"

The term "scientific method" has on occasion been used to signify an intelligent way of carrying on some practical activity; i.e., technology. When it appears in statements of educational objectives, however, "scientific method" should be understood probably as a short form of the phrase "scientific method of inquiry."

The scientific method of inquiry is one way of knowing. It is contrasted, for example, with tenacity, authority, and intuition as grounds for belief [6:191–196]. It is regarded by many philosophers as the source of dependable knowledge [2:vii, 51]. In fact, knowledge often is defined as the product of such competent inquiry.

After a survey of numerous books on philosophy and research methods, books on teaching science, and analyses of the scientific method,[2] a three-part statement of the procedures of scientific inquiry was prepared, viz.:

Define a problem.

Propose a solution to said problem.

Test the proposed solution.

Development of it was arbitrary. The statement was intended to be used in organizing further discussion, and the detailed analysis which follows. It was not intended to be used as a plan for teaching or for carrying on research.

Current Definitions of "Scientific Attitude"

"Attitude."—The meanings commonly accepted for the terms "attitude" and "scientific attitude" may be approached through formal definitions and through examples of their use. The following definition is from the recent *Dictionary of Education*, viz.:

> ATTITUDE: a state of mental and *emotional readiness to react* to situations, persons, or things in a manner in harmony with a *habitual pattern of response* previously conditioned to or associated with the stimuli [22:37. Italics not in original].

This definition of "attitude" is subject to interpretation as denoting a habitual, or fixed, response. In this connection, Howard and Robertson have referred to "a 'mind set,' a tendency to act in a certain way when faced by a problematic situation . . . or a predisposition to action" [25]. Also, Crowell has spoken of "certain specific mental attitudes which will *impel* [*one*] *to behave in a definite manner* under certain conditions" [11:15. Italics not in original].

Another element in the definition is that of emotion; typical expressions of this idea follow:

> . . . that attitudes are emotionalized outcomes of experience, that they are the by-products of

[1] Grateful acknowledgment is made of suggestions concerning this paper received from the following: Professors John L. Childs, Irving D. Lorge, S. Ralph Powers, and Helen M. Walker, all of Teachers College, and Professor Ernest Nagel of the Department of Philosophy, Columbia University. This paper is a revision of *Analysis of the Scientific Method of Inquiry*, a booklet which was used in the study reported in *Variability in Recognizing Scientific Inquiry*. New York: Bureau of Publications, Teachers College, Columbia University, 1949.

[2] Representative statements from these types of materials may be found in the following sources:

Books on Philosophy and Research Methods [1], [16], [23], [39:37], [42:57], and [50].

Books on Teaching Science [10], [18], [20], [40], and [45].

Analyses of the Scientific Method [30], [35], and [46].

learning that predispose one to behave in a particular way in a situation as a result of previous experiences . . . [47].

An attitude can translate itself into conduct only if it is tinged with emotion and becomes a habit. Unless an attitude has behind it emotional drive, unless it is practiced, it cannot be an effective force . . . [7].

One of the functions of science teaching should be to develop in the student certain specific attitudes toward a definite type of situtaion. The individual should possess a feeling of favor or disfavor toward the situation and be ready to react to it in a definite way [11:17].

Still a different element in the preceding definitions of "attitude" is that of influencing conduct; the emotion furnishes the drive to action and the fixed response determines the direction of action.

"Scientific Attitude."—The customary development of the term "scientific attitude" from the simpler term "attitude" is exemplified by Good's definition, viz.:

ATTITUDE, SCIENTIFIC: the mental attitude characterized by willingness to search for truth without prejudice, to change one's opinion on the basis of new evidence, to seek cause-and-effect relationships and to discriminate between fact and theory [22:37].

It is assumed that the several traits given here as characteristic are to be interpreted as before to mean fixed responses, charged with emotion, motivating and directing conduct. These interpretations will be considered further below.

Composite Nature of "Scientific Attitude."—Reaction to the scientific attitude as a whole is found in common usage. It is suggested even in the writings of thoughtful men—even in Barry's title, *The Scientific Habit of Thought* [2], and in Good's definition as "the mental attitude . . ." [22:37]. But, Barry, Good, and nearly all educational researches [3] to define the term "scientific attitude" have done so by specifying discrete items. It seems justifiable to use the term to refer either to one of the elements defined in such studies or to the composite of them.

Clearly, one may accept some of the specific attitudes without accepting others. For example, a person may accept the verification of some logical consequences of a hypothesis as evidence for the hypothesis, but then may think that the hypothesis has been demonstrated to be true. Or, he may accept evidence for hypotheses with reference to one kind of experience, but reject evidence concerning other kinds of experience.

A Redefinition of "Scientific Attitude"

What is the relation between scientific attitudes and scientific method? It has been stated that possession of desirable attitudes is sufficient for the method [11:13–14, 15–16, 17]. Elsewhere this close connection has been denied [28:37–38], [29]. A moderate and sound position is that the scientific attitudes are an essential part of the scientific method of inquiry. When knowledge is abstracted from the traditional three-fold view of science, there remain certain procedures and attitudes which constitute the scientific method of inquiry. In this connection, some of the ideas customarily associated with the term "scientific attitude" seem undesirable.

One who regards the scientific method of inquiry as provisional and subject to revision, should not permit his responses to situations, or to certain elements in them, to become fixed or habitual. For "fixed" usually means "not capable of change"; and "habitual" refers to a pattern of behavior "performed without conscious thought, hesitancy, or concentration" [22:197], which pattern—although not fixed—can be changed only with considerable effort. It is not fantastic to think that some part of the time-tested scientific method of inquiry may need to be changed. Fisher's condemnation of single factor designs in agricultural experimentation seems to exemplify such a change in our own time; he maintains that multiple factor designs not only are more efficient, but provide information—about interactions—which is absolutely unobtainable from single factor designs [21]. One who had fixed a single factor design as his response to a situation requiring test by experiment might find it difficult, if not impossible, to adopt the new technique. Similarly, it seems unwise for

[3] For example, [8], [9], [13], [15], [17], [31], [32], [37], [44], [46], and [48].

one to permit such a response to become charged with emotion, at least with the emotion of blind acceptance.

But one needs motivation and direction for his actions. Can this function be served without emotion? If it can be, then the term "scientific attitude" applied to the servant seems to be misleading, because the term "attitude" does connote emotion, viz:

> ATTITUDE suggests a personal, or sometimes, a group or communal point of view, especially one that is colored by personal or party feeling, is influenced by one's environment or the fashion of the moment, and is, on the whole, more the product of temperament or emotion than of thought or conviction [49: at POSITION, p. 633].

One might as well use the terms "scientific prejudice" or "scientific bias"; Barry's title, *The Scientific Habit of Thought,* was used in just this sense. Even so, the definition as a "point of view" seems to be clearer and more applicable than the preceding definition as "a state of readiness . . . to react . . ."

Of the possible terms that have been considered "standpoint" comes closest to being acceptable.

> "STANDPOINT" more often connotes than definitely implies a fixed way of looking, justified by one's fundamental principles, one's wealth of information, or the like, and not necessarily resulting in a limited understanding [49: at POINT OF VIEW, p. 629].

This term, unfortunately, connotes a fixed response, but it suggests a thoughtful rather than an emotional ground for behavior. The scientific standpoint for the procedures of scientific inquiry consists of the ideas which guide the general application of the procedures.

The term "scientific attitude" is possibly too well entrenched to be dislodged from its position in discussions of scientific inquiry. But it might be an advance if it were redefined to denote: (a) "an idea, hypothesis, or principle of conduct which is used to guide the general procedures of scientific inquiry; (b) such ideas collectively." Naturally such elements are revised or discarded when shown to be inadequate; they affect conduct, but do not obstruct desirable changes in conduct.

STUDENTS' SOURCES OF SCIENTIFIC INQUIRY

Attempted Objective Formulations

Several attempts have been made to develop formulations of scientific method and scientific attitudes by objective procedures[4]; some students have assumed that subjective formulations were incompetent [12], [14], [28:32], [30]. In the objective formulations, the literature was studied to find suggestions of ideas involved in scientific inquiry. The ideas were listed. Then judges rated the items of the lists for importance, desirability as objectives of instruction, pertinence to scientific inquiry, or the like. The lists were revised more or less in accordance with the suggestions received; sometimes another evaluation of the revised list was secured.

Such studies have had considerable value in directing attention to certain aspects of scientific inquiry. It is questionable whether—because of their objective procedures—they have any greater validity as definitions of scientific method and scientific attitude than have the so-called subjective studies.

Freedom from Subjectivity.—One wonders just how free from subjective and chance influences these studies really were. Surely the investigator's philosophical experience and tastes—if not the limited contents of his libraries—influenced his selection of background material to scan for suggestions; no investigator has claimed to have read everything in print on the subject. Further, his interpretation of what he read was probably individual; yet only those ideas which he approved were offered for the judges' consideration. Ebel remarked that although the several lists were derived from approximately the same pool of literature, the lists were decidedly different [19].

Validity of Composite Judgments.—Another serious question involved in such studies is whether the technique of securing composite judgments is valid. Even if the judgments have validity with reference

[4] For example, [9], [11], [13], [14], [28], and [44].

to what the judges think is important, desirable, or pertinent, that validity is not necessarily related to validity as guides for scientific inquiry, as Ebel has pointed out [19].

The evaluation is essentially a resort to the method of authority. Yet, each of the investigators, in deciding to make a revision only when more than one person had suggested it or in deciding not to make a revision when some had suggested it, has set his own thinking against the pronouncement of authority. This kind of intelligent judgment is fatal to the method of authority; if authority is disputed on any point, why not on all points [41:51]?

An extreme example of this questioning of the very authority upon which the validity of the study has been based, is found in Keeslar's decision to retain in his list of elements of the scientific method an element whose relative value was below the minimum which had been established for retention.

> It was deemed advisable to retain the twelfth major element (making inferences or additional hypotheses from the results of the experiments [28:128]) . . . although it had received a relative value of only 41.7. On the basis of the comments . . . It may be submitted, however . . . Hence it seems advisable to retain the twelfth major element in the final version of the list . . . [28:135–136].

Keeslar's list seems to be a better list for the inclusion of this element. But it makes no difference what reasoning he had in the ellipses above; by admitting any reasoning at all he destroyed the basis for the validity of his study.

Considered Answers.—A third question is whether or not adequate provision was made to secure thoughtful answers. Ebel pointed out that

> Reflective thinking is hard work and takes time. The experts to whom the questionnaires are addressed, being busy with their own endeavors and not directly interested in the matter being probed by the questionnaire, will tend to answer in haste which precludes the exercise of the necessary reflective thinking. The questioner has no right to expect, and apparently does not often get thoroughly thought out answers to questions that require judgment [19].

In this context a statement made by Keeslar becomes pregnant with meaning. He said that Curtis' list of ten elements of scientific method was validated by submitting it to "twelve teachers of pure-science on the Faculty of the University of Michigan, all of whom approved of the list without objection" [28:39]. Keeslar assumed that lack of objection here meant active approval. But, did it? Other assumptions are possible!

Influence of Criticisms Received.—When, in spite of all difficulties, thoughtful criticisms were received, were such criticisms allowed to affect the formulation very much? Ebel noted that the differences in the preliminary formulations were not appreciably reduced by any modifications the judges might have suggested [19]. Also, when the comments which Keeslar received are compared with the items in his final formulation, it appears that several excellent suggestions were not used. For example, Keeslar said to test a hypothesis "by carrying out the experiment with great care and accuracy" [28:138–139]; one of his respondents had suggested, with "accuracy sufficient for the problem" [28:98] There is strong support for the respondent's view: e.g., Hogben has said:

> Exact science, as the term is usually employed, is a misnomer. Science is as exact as it *can* be with the instruments available or *need* be for the uses to which it is put. [24]

Return to a Subjective Formulation.—Consideration of the issues above resulted in a decision to develop a formulation of scientific inquiry by avowedly subjective means. Preliminary study would be extensive and catholic. The development of concepts in the investigator's thinking necessarily would be arbitrary and personal, but the concepts would be written out for submission to criticism by the most competent persons who could be persuaded to read them. Then the investigator would use as much of their criticisms as he was able to, but responsibility for the resultant formulation would be his alone.

Scientists or Philosophers

"What does a philosopher know of scientific inquiry? Has he ever conducted an experimental investigation?"

"What does a scientist know of scientific inquiry? Has he ever stuck his nose outside his laboratory?"

With such derogatory questions is the perennial debate waged as to the relative fruitfulness and authority of two sources of ideas important in scientific inquiry. Other sources which have been used in educational researches are included in the list by Lampkin [31:26], but such sources are clearly secondary to the technical, popular, and biographical or personal writings of scientists and philosophers.

Even if one should admit prëëminence to the practicing scientists, there are serious difficulties to be overcome in studying their work, as Lampkin has pointed out [31:30–31]. Likewise, Crowell has reported the great expenditure of time and effort involved in a first-hand analysis Downing and his students were said to be making of the procedures followed by scientists [11:30].

All things considered, the best single source seemed to be the published works of philosophers. Scientific inquiry has been thoroughly analyzed by philosophers; their writings assay high in discussions of it.

SUMMARY OF IDEAS IMPORTANT IN SCIENTIFIC INQUIRY

The bulk of the following analysis of the scientific method of inquiry has been derived from a study of philosophical works. The criterion for including an idea was that it should be related to important philosophical issues and should affect the conduct of scientific inquiry.

The analysis has a certain face validity in that it discusses all of the scientific attitudes and procedures of scientific method tabulated in the educational references appended hereto. Also, all of the important philosophical issues discussed in the analysis have been treated in standard works on philosophy. Further, the analysis in its present form embodies modifications which have been made to meet criticisms made by several readers of earlier versions.

The ideas in the analysis have been organized into eight groups, which in turn have been classified under the rubrics of the three steps of the scientific method developed above, and have been compared critically.

Only one who has worked at such tasks knows how these elements flow and change form under the consideration of the student, as do the flames in the hearthfire. Yet, as the heat and light persist in the fire, so some general patterns persist in the analysis. The scientific method of inquiry is shown as having the following characteristics:

Fallible, self-corrective, and progressive, rather than infallible and conservative.
Probable, rather than necessary.
Sceptical, rather than dogmatic.
Public, rather than private.
Both empirical and rationalistic.

The issues involved in these and other positions accepted herein are stated below. The language is made simple, in order to impede the novice in philosophical matters as little as possible. When he accepts various elements of the scientific method of inquiry he thereby becomes liable for certain philosophical beliefs. Such important commitments should not be assumed unwittingly.

THE FIRST STEP IN THE SCIENTIFIC METHOD OF INQUIRY IS TO DEFINE A PROBLEM

The scientific method of inquiry is one of asking and answering questions, or of setting and solving problems. It is based on common-sense experience, as discussed below; but it begins only when doubt has been felt or a problem has been encountered and defined.

1.00 [5] *Scientific Problems Involve Abstractions from Common-Sense Experience*

Scientific inquiry deals with abstractions rather than with events themselves. Ex-

[5] To each guiding idea stated in the analysis has been assigned a number which identifies it and shows its relation to other numbered ele-

amples of abstractions are physical dimensions, number, inertia, color, cause-and-effect relationships, plant succession, organic evolution, and anger. An event might be exemplified by an earthquake or a human being; it is interpreted as a particular occurrence or a particular thing.

1.10 The materials of scientific inquiry consist of immediate sensory experiences and of what is inferred from them.

Examples of sensory experiences would include seeing a dog, hearing his bark, feeling his hair, and smelling his odor. Such experiences are *immediate,* in that they involve little thought. Examples of inferences based on the immediate sensory experiences would include seeing that the dog was limping and thinking that he might have a sandspur in his foot, or feeling that his hair was wet and thinking that he probably had been running in the shallow water of the bay. Such inferences are *mediate,* in that they involve thought.

The distinction between mediate and immediate experience is not important here, since both kinds of experience are included in the materials of scientific inquiry. If the inferences had been excluded, the view would have been called *extremely narrow* or *sensationalistic.*

1.11 Scientific inquiry has no assured starting point; it is both empirical and rational.

This basic material of scientific inquiry has been termed "common sense." It has been described as

> . . . the body of knowledge gained through our daily experience and the cumulative experience of the race.
>
> . . . Its source is experience of the most fundamental and pervasive character, the minimal biological, social, and psychological experience of man. All that is necessary for its acquisition is the exercise of the senses and the memory, and the simplest kind of reasoning. . . . It results not from inquiry but from merely living. It is completely uncritical, and there is no knowledge more elementary than it. . . . Thus common sense is the starting point of all inquiry. We may, by the employment of deliberate methods, rise above it; but we can never dispense with it. [41:9]

In the quotation above, scientific knowledge was specifically excluded from common sense. Yet the definition might be stretched to include it, for no part of it is certain or exempt from reexamination; also; accepted hypotheses are built into more complicated ones. Like Santayana's philosopher, the scientific inquirer is "compelled to follow the maxim of the epic poets and plunge in *medias res.*" [43]

Thus, science might be said to be based on experience conceived as the interaction between the human organism and its environment. A science based on experience is said to be *empirical.* A science logically developed from *a priori* concepts would be called *rational.* The science being discussed here is both empirical and rational, in that ideas growing out of experience are logically developed and referred back to experience for test.

1.12 Public experience, rather than private, is the basis for scientific inquiry.

Throughout this analysis, the scientific method of inquiry is shown to be public in every possible stage. A private experience which remains private cannot be material for scientific inquiry. Mystical experiences or intuitions, insofar as they cannot be analyzed or communicated, remain inaccessible to scientific inquiry. In contrast, the scientific record is open to all. Any problem not growing out of common-sense experience, enriched by scientific inquiry, is dismissed as being cut off from scientific inquiry and therefore indifferent.

The function of the individual is to introduce ideas, which then are subjected to public appraisal.

1.13 Scientific inquiry is not limited to purely physical phenomena.

Nothing has been said here to limit sensory experiences to purely physical phe-

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ments. For example, 1.11 is subordinate to 1.10, which in turn is subordinate to 1.00. If in a number the hundredths place has any digit but zero, the idea so numbered is in the least inclusive group and is subordinated to the idea having the same digits it has in units and tenths places but with zero in hundredths place. Similarly, when tenths place has any digit but zero . . .

nomena, nor should they be so limited. Our experiences have a physical basis. *Materialism* argues that they are nothing more than physical. Materialism seems contrary to fact. Rejecting materialism opens the way for study of biological, social, and psychological phenomena.

1.20 Scientific inquiry is interested in events because of the characteristics which they share with other events.

Because it deals with abstractions, relations among events, and classifications of events, scientific inquiry is said to be *analytical.* The basis of classification is not foregone; the institution of a classification is evidence of a hypothesis that variation in the basis is important. One should remember, also, that events alike on one characteristic may differ on other characteristics.

Anti-scientific sceptics condemn the analytical approach as being artificial, unnecessarily complex, and utterly incapable of dealing with anything other than the simplest physical events. They assert that the whole is more than the sum of its parts and that biological and social events especially can never be understood simply by putting back together the scientific abstractions of them. They wish to study particular events.

On the view presented here, every particular event is excluded from scientific inquiry [3:37 ff.].

1.21 The analytical procedure of scientific inquiry is necessary to knowledge.

Adherents to the scientific method of inquiry assert that if each event is unique, then experience with one event means nothing with respect to another. Analysis is necessary for knowledge—and for the symbolic transmission of knowledge.

The analytical procedure involves the assumption that *complicated events are compounded of simpler events,* or that some causes act independently. The assumption is justified by the success of predictions based on it.

1.22 Values enter science at least in the formulation of problems.

Deciding what abstractions to deal with is one kind of problem faced by the scientific inquirer. He has no way of telling which of the many problems he might formulate will be possible for him to attack successfully. Even if he were sure of success with a particular problem, he has no way of knowing whether the solution would be very important in itself or would lead to other worthwhile problems.

Emotional values often direct the selection of a problem. A medical man may study a particular disease because it has cost him a loved one or takes too many of his fellow-men. Or, a physicist may attempt to produce an atomic bomb for patriotic reasons. Economic and other values play their parts, too. Childs points out that

> It is a superstition to suppose that scientific investigators approach problem situations with naked or unbiased minds. The problems they select for study, the questions they ask . . . are all conditioned by the presuppositions of their minds [4].

THE SECOND STEP IN THE SCIENTIFIC METHOD OF INQUIRY IS TO PROPOSE A SOLUTION

2.00 Proposed Solutions Involve Abstractions from Commonsense Experience

The problems concern relations among abstractions. For example, "Do the properties of a chemical element bear any simple relation to its atomic weight?" The solutions proposed for such problems also employ the abstractions. But new characteristics may be abstracted. For example, the solution to the problem stated has been, "Yes, but the atomic number of an element is a better indicator of its properties."

2.10 The characteristics of a class may be inferred from a proper sample of the class, but the inference is only probable, not certain.

In formal logic, this process of working from the characteristics of events to those of a group of events is called *induction.* It is used in common thought as well as in

scientific inquiry. It is the approach used in fields where relatively little theory exists or where events are extremely complicated; for example, induction has been for centuries the characteristic method of biology [2:156–157].

The general problem of induction has never been solved. That is, when inductions are based on events, there is no internal check on the validity of the induction. Scientific inquiry recognizes this difficulty. Validity based on origin is not accorded to inductions. Inductions are only probable inferences to be tested as are other ideas.

2.20 From his experience a scientist may predict that if certain complexes of conditions exist, then certain other complexes will, or do exist.

The cause-and-effect relations of scientific inquiry are summaries of past experience and predictions for the future. When first made, these generalizations are called hypotheses; as they become more generally accepted, or are supported by more evidence, they progress through the stage of theory to that of law or fact. (Cf. Section 6.00.) The search for correlations of this sort is the object of all scientific inquiry.

Any hypothesis may be conceived as an assumption to be tested. In the past, a distinction has been made between *physical theories,* involving a hidden mechanism to explain observed events, and *mathematical* or *abstractive* theories, involving relations abstracted from the events. The distinction seems unimportant now that theories are viewed as functional means to prediction of future events.

2.21 The principle of causality is deterministic, but it does not imply mechanical determinism (also known as rational mechanism and as dogmatic mechanism).

Determinism is simply the assertion that causal patterns exist. It does not imply that such relations may not change, that the number of such relations is fixed, or that we are in possession of all possible such relations. The idea that determinism did imply these things seems to have led ingenuous people to speak of the downfall of the principle of causality and of classical physics when physical theory was enriched with the idea of indeterminacy, of the statistical nature of certain chemical laws.

The deterministic view that every event is conditioned by preceding events does not justify the doctrine that "causes" are superior to "effects"; such interpretation is often used in support of supernaturalism as *belief in a first cause.* Rather, we read evolution and emergence into the interactions of events.

Sometimes it is claimed that the principle of causality is known to be true *a priori.* It is said that we could not possibly know from experience that every event has a cause; that in order to know this it would have been necessary for us to have examined all events in the entire past and entire future; that experience makes it likely, but not certain. In reply to this rationalistic contention, the empiricist simply admits that the position is not certain, is merely probable. The belief that the past may be a guide to the future is one element in the scientist's faith as *belief on account of evidence;* the other element is seeking verification of such predictions.

2.22 The typical characteristic of cause-and-effect relations is that they hold without exception.

There is no way of establishing cause-and-effect relationships conclusively, but there are various grounds on which proposed laws may be discarded.

If two complexes of conditions, C and E, do not vary concomitantly, then C and E are not causally related. *Concomitant variation* is essential for, but not sufficient to establish, a causal relation. Probably people who assert that quantitative thinking is the essence of science have in mind the quantitative relations employed in establishing concomitant variations. The fallacy known as *post hoc, ergo propter hoc* is a special case of the fallacy that concomitant variation establishes a causal relation.

If E ever occurs without C, then C and E are not causally related. In logic, this criterion is called the *method of agreement.*

If C ever occurs without E, then C and E are not causally related. This too has a special name, the *method of difference.*

2.23 A scientific law does not rule nature.

This is a warning against hypostasizing the concept of scientific law, that is against imagining that the stated relation has any power to bring about the effect when the cause is given.

2.24 A scientific law does not imply any teleological connection between a "cause" and its "effect."

The distinction between *efficient* and *final causation* is recognized; that is, each example of the cause-and-effect relation requires the potentiality for the effect ("final cause"), and the conditions necessary to realize that potentiality ("efficient cause").

Sometimes the results of a change are confused with efficient causes. The ends are regarded as forces or purposes bringing themselves about. This view is excluded by the above attitude.

2.30 No known rules can be followed mechanically to arrive at useful hypotheses.

Scientific inquiry is progressive in character, not only because of its self-corrective procedures, but also because it admits new ideas. In contrast, formal logical systems include no growing ideas.

If there were rules to be followed mechanically, then Lord Bacon's ideal institution, in which the obscurest depths of knowledge were to be fathomed by the cooperative labor of morons, would be possible. Certain favorable conditions for a fruitful discovery may be stated; but, even when one has satisfied them,

> there is not the least guarantee that he will hit upon it or when he will do so, or that he rather than another will do so . . . all we can say is that scientific insight is unpredictable, that . . . there is no rule for the attainment of insight at a specified time [41:73, 111].

2.31 Useful hypotheses result from inspiration, or just plain guessing.

Scientific inquiry would be seriously hampered if it still clung to the belief that hypotheses are treacherous and to be avoided whenever possible.

Various terms have been used to describe insights into problem situations. The terms include "inspiration," "intuition," "flash of genius," "inductive inference," and the like. The distinctions among them are not important in scientific inquiry because the source of hypotheses is indifferent as far as validity is concerned. No hypothesis is accorded validity based on its source; all hypotheses are subject to verification.

The cumbersomeness, extreme difficulty, and only probable nature of inductive inference has been mentioned above. For such reasons, it has largely been displaced by guessing and testing the guesses.

> . . . excepting in methodically developed procedure this inductive thought is not the patient unimaginative collection of particular experiences and their subsequent classification by the routine tabulation of common characters. A philosopher in meditative leisure might imagine such a procedure, and a completely baffled scientist might adopt it as a last resort. But usually, in common and scientific thought alike, it is possible to alleviate this tedium by guessing; and almost always this is done . . .
>
> Our favorite procedure nowadays is to guess both quickly and frequently, depending almost wholly upon our procedures of verification to establish the truth or probability of our successive conjectures, or to invalidate them. This is now a more effective proceeding than that of cautious inductive inference; because as a consequence of the high development of methods and devices for verification, it is much more rapid. Formerly for lack of these means, it was better method to proceed more slowly and surely; and even now this course is advisable whenever confirmatory procedure is difficult. If satisfactory verification is impracticable, obviously, the only possible procedure is that of complete induction; but this is never resorted to if it can be avoided. Thus the method of hypothesis and verification has now become the typical scientific procedure in the analysis and correlation of phenomena; and its critically important phase, which now, one might almost venture to say, alone distinguishes it from the very similar procedures of the imaginative arts, is that of verification [2:103, 108–109].

In many cases, even the temporary element of psychological conviction and feeling of insight may be absent. Scientists have entertained theories deliberately and actually invent them in order to round out the number of possibilities of explaining a phenomenon. When Kepler entertained the theory that the orbit of Mars was elliptical, he did it not as the result of a sudden insight or feeling that it was so, but with considerable uncertainty and with the same patient scrutiny he had given to other theories [41:110].

Unsympathetic critics of scientific inquiry have hurled at it epithets such as "unimaginative." Yet imagination is indispensable in the contemporary conception of scientific inquiry. Scientists as well as poets speculate; but the scientists' flights of fancy are soon turned back to public testing of their logical consequences.

. . . Disciplined imagination has been at the bottom of all great scientific discoveries. All great scientists have, in a certain sense, been great artists; the man with no imagination may collect facts but he cannot make great discoveries. If I were compelled to name the Englishmen who during our generation have had the widest imaginations and exercised them most beneficially, I think I should put the novelists and poets on one side and say Michael Faraday and Charles Darwin. . . . The discovery of some brief statement, some brief *formula* from which the whole group of facts is seen to flow, if the work, not of the mere cataloguer, but of the man endowed with creative imagination [39:30–31].

2.32 Thorough knowledge of a field of subject matter is conducive to the formation of useful hypotheses in that field.

This would seem axiomatic, if it were not so often disregarded. As pointed out above, pure observation is a myth: sensory experiences mean nothing without associated ideas. If the common-sense ideas are wrong, they may hamper development of better ideas. But common-sense enriched by scientific inquiry is the only raw material available for building new and better ideas.

Ogburn's discussion of the origin of inventions is pertinent here. An invention is defined as "a combination of two or more existing elements which form a new one."

This conception of an invention enables us to distinguish one condition which affects the production of inventions, namely, the existence of prior inventions. Obviously more inventions are possible when there are more elements to combine together [38:16–17].

Inventions occur then when the elements necessary for the invention exist, when there is inherent mental ability, and when the social evaluation trains and directs the inventor to the task. . . . Existing knowledge was not sufficient to have predicted that the steamboat would have been invented at exactly a certain year, although our knowledge would certainly have led us to forecast that a steam engine would be applied to a boat within a short space of time after it was applied to other forms of industry. The fact that many inventions are made by different inventors independently at the same time is due to the happy concurrence of these three factors, particularly the appearance of all the elements necessary to the invention [38:21].

2.33 Valuable laws and hypotheses often spring from a spirit of curiosity, or of inquiry for its own sake.

The influence of values on the formulation of scientific problems has been noted above. The desire to attain accepted values, e.g., the satisfaction of curiosity, may be regarded as motivating the proposal of solutions to be tested.

2.34 Critical dissatisfaction with things as they are often is valuable in scientific inquiry.

If admiration of the elegance of things as they are leads one to investigate them, then such admiration may be useful in scientific inquiry, much as curiosity is. But if admiration does not motivate investigation, if it is relatively passive, then it is of little use. The *gadgetry of science* is to be decried.

Similarly, dissatisfaction cuts both ways. If one's dissatisfaction is expressed only in griping, then it may even be harmful. But if it stimulates one to investigate and attempt to change things for the better, then it may be most valuable.

Perhaps all this is just another way of saying that one begins scientific inquiry when he has defined a problem and that he must have some motive for continuing his efforts to solve the problem.

THE THIRD STEP IN THE SCIENTIFIC METHOD OF INQUIRY IS TO TEST THE PROPOSED SOLUTION

3.00 Accept as Evidence for the Proposed Solution Only the Verification of Some at Least of Its Logical Consequences

Scientific inquiry is *empirical,* in that the only evidence it accepts is based on experience. It is *pragmatic* in that it defines truth as verification of predictions, as success in inquiry. The *verification is public,* in that the general procedures are published together with their application to particular problems, and in that anyone who wishes may, after suitable preparation, check the work.

This cluster of ideas seems to be an important part of what is commonly described as a scientific frame of mind, impartiality, or the ability to form judgments unbiased by personal feelings. From this point of view a scientific conception is one which there is good reason for believing true; an unscientific conception is one which is held for some reason other than its probable truth [42:15].

Harmony of a new idea with previously accepted knowledge, as pointed out in Section 7.10, is essential; but, the harmony may be achieved by revising either or both. This self-consistency is not in itself grounds for belief; rather, demonstrated inconsistency is the signal for revision of one at least of the inconsistent ideas.

3.10 A hypothetical proposition should have consequences capable of being tested—should not explain every possible result.

Scientific inquiry requires that all its hypotheses should be meaningful. A hypothesis is meaningful if it is possible to collect evidence for it, possible to investigate its truth or falsity [41:123]. The *meaning of a proposition is defined pragmatically* as the sum of its verifiable consequences [5:45]. If it has no verifiable consequences, it has no meaning and is excluded from scientific inquiry. If no differences can be found in the consequences of two propositions, then the propositions mean the same.

Cohen and Nagel point out that many popular theories fail to meet this test. For example, the theory that whatever happens is the work of Providence does not enable us to predict and is unverifiable. For, it does not differentiate between itself and the theory that whatever happens is fortuitous [6:211–212].

The consequences of a proposition are determined by using the *deductive procedures of formal logic.* It is true that the consequent meaning is contained in the statements originally accepted; deductive logic adds nothing to it. But, by means of deduction,

> all imaginable permutations and combinations of fixed ideas may be worked out by machinery, mechanical or symbolic; and by these routine processes—this is the real importance of logic—attention is directed to implications which are missed in common thought, and the mind becomes capable of dealing with complexes of relation far too intricate to be directly conceived [2:170].

The deductive elaboration of a hypothesis is continued until some statements are obtained which refer to matters of observation. If the deductions are corroborated by observations, then some weight is given to the original hypothesis.

The hypothesis is not demonstrated by verification of some consequences, for it is a *fallacy to affirm the consequent.* Also, not all possible deductions from a hypothesis can be made, it is possible that some deduction not yet tested would not check with observation. Such disagreement would men that the hypothesis was false, for a true statement cannot have false implications; the hypothesis would need modification, as pointed out in Section 7.20.

Several of these points are illustrated in Galileo's classic experiments on motion of falling bodies. Being unable to measure instantaneous velocity, he was nevertheless able to deduce from the idea $v=kt$ that $s=\frac{kt^2}{2}$, which could be tested even with his crude equipment. His work showed that the final velocity was propor-

tional to the distance fallen, which idea he had discarded previously as absurd. From his results, the idea that a moving body tends to continue in motion could have been deduced, but Newton—years later—was the first to state it [2:239–247].

Contrasting points of view are maintained by some forms of *positivism,* which do not admit indirect verification of theories, and therefore reject all speculative theories; and which test the meaning of a proposition by its "usefulness" or "fruitfulness."

3.11 The statement of a hypothesis should be clear and unambiguous.

The analytical procedure of scientific inquiry makes possible its use of symbols for the transmission of ideas. The symbols represent abstractions and their relations. In so far as mystical experience and intuition cannot be analyzed, they cannot be expressed symbolically or communicated.

Any abstraction should be held unchanged during the inquiry in which it is used and should be represented by a clearly defined symbol, or term. The *functional definition* of abstractions and symbols is accomplished by specifying procedures for identifying them in terms of public experiences. Rather than being interested in words for themselves, as is the philologist, the scientist is intent on defining them well in order to convey definite conceptions.

Scientific statements *denote rather than connote;* their meaning is literal rather than psychological. They should evoke the same intellectual response from all; in contrast with religious writings, they require no ecclesiastical interpreters.

Scientific statements are intended to be tested. They are usually more specific than common-sense statements; therefore, they are more easily controverted. As Johnson has pointed out, there cannot be a precise answer to a vague question [27].

3.12 Successful prediction of phenomena, especially in fields different from that in which it was derived, is strong evidence for a hypothesis. Even if data of record support a hypothesis, new observations or critical experiments are desirable.

When a hypothesis has been elaborated inductively, it may be that some of the deductions can be checked against data already on record from preceding observations or experiments. That is, starting with the theory and some of the known data, other portions of the known data can be "predicted," just as if they were not known.

However, any number of hypotheses can be devised to explain relations already known. The acid test is to be able to predict events before they occur.

3.13 Observations and experiments are planned to test the logical consequences of hypotheses.

In ordinary speech, the word "experiment" is used for almost any sort of test or trial. In scientific inquiry, an experiment is the study of a particular event under the controlled conditions described in the section next below.

Experimental verification is extremely important, but many kinds of events cannot be studied experimentally because they are controllable only partially or not at all. Particularly astronomical phenomena, but also geological and physiological events, can be studied only by more or less uncontrolled observation.

3.20 In an experiment, all relevant independent variables but one should be controlled while the one is varied.

The experimenter varies only one condition at a time in order to be able to say: *"Other things being equal,* a change of so much produces such an amount of effect." Only under those conditions does he assume to draw a valid conclusion. In most of the experiments of modern science the expensive, time-consuming task is this elimination of any irrelevant and uncontrolled factors [36].

Some writers consider Mill's recommendation to be a counsel of perfection. They say that when it is impossible to hold constant all but one independent variable, the others are controlled by measuring them simultaneously with the one. In such experiments complicated statistical pro-

cedures are required to analyze the results.

Fisher and others say, however, that it is inefficient and sometimes futile to carry out single factor designs, because no information on interactions can be obtained therefrom [21].

3.30 Scientific observation should be as sensitive and objective as is desirable.

Often it is desirable to make approximate observations; in general, observations are made with the least sensitivity, or widest margin of error, that will satisfy the purpose of the observations.

Accurate observation and measurement are sometimes characterized as the most important of all scientific practices. Important as the quantitative techniques are, in general they are only contributory to uncontrolled or experimental observation carried on to test hypotheses or supply material for inductive generalizations.

3.31 Many observations are made indirectly.

This attitude may be regarded as a corollary of Section 3.10, which admits indirect verification of hypotheses through verification of their logical consequences. The substitution of one set of phenomena for another would also be suggested by the general formulation of a scientific law (cf. Section 2.20).

Some forms of *positivism,* which would in general limit scientific inquiry to theories which are ultimately directly testable and to matters directly observable, are denied by the present attitude.

3.32 The scientific inquirer should be honest in observing and interpreting events.

An obvious meaning of this attitude is that pointer readings should not be falsified. In terms of propaganda techniques, the "card stacking device" should not be used [26].

Another meaning is that the scientist should recognize distinctions in events and not overlook distinctions which are relevant to his inquiry. It is not true that the scientist's response is proportional to the energy level of a stimulus; for example, the astronomer's response to a star is not necessarily in proportion to the apparent magnitude of it. Scientific inquiry is deliberate and not mere reception of sense stimuli. The scientist's response is affected by the meaning he reads into events. He should weigh carefully all factors involved and not permit himself to be misled by prejudice or strong preconceptions.

3.33 All measurement is relative and should be carried out by objective, repeatable procedures.

The *idea of number,* or of counting, is closely associated with scientific observation.

Barry stresses the idea that every sort of observation is made by reducing it ultimately to the observation of relative linear dimensions, which are measurable with very high precision [2:99]. Thus change in temperature is represented by movement of the meniscus of a column of liquid, movement of the needle of a microammeter connected to a thermo-couple, or the like. This idea is basic to the characterization of scientific inquiry as *reading positions of pointers over dials.*

Also important is the idea of comparing directly, or indirectly, with almost invariable *standards.* For standards of length, we have the meter bar in Washington or a certain line in the spectrum of incandescent calcium; from them we have derived gage blocks, micrometers, steel tapes, yardsticks and the like. However, even when phenomena are not reduced to relative lengths, observation is facilitated by comparing with standards of some sort. For example, observers may match colors, illuminations, and pitches.

3.34 The use of instruments permits a great increase in both sensitivity and accuracy of observation.

The use of most instruments clearly involves the assumption of concomitant variation in two or more quantities. Thus the fundamental unit of electricity is defined in terms of electro-chemical changes, while the common methods of measuring electricity employ its magnetic effects.

We are reminded of our weight and perhaps of gravitational attraction with every step we take. But, the Eötvös balance shows readily the changes in g for a single step north or south in latitude 45°, where that change is about one part in a billion [51].

Further, every radio receiver exemplifies instruments sensitive to energy to which we respond not at all.

3.35 The effects of unavoidable errors of observation may be minimized by applying to them the theories of probability.

The primary reason for repeating observations of a particular kind is to permit an estimate of the error of the observations. With a given observational set-up, a single observer repeats his observations to determine his personal error of observation. With the same set-up, other observers may have different personal errors.

It is often said that one should not generalize from only a few observations, the inference being that *the more observations the safer it would be to generalize.* Even though one recognizes that no generalization can be demonstrated beyond doubt (cf. Section 6.00), still the route to greater probability seems not to lie through mere repetition of observations. Rather, different procedures should be devised to study the same phenomenon, or entirely different logical consequences of the original hypothesis should be tested.

3.36 Careful and detailed records should be kept of ideas and of experimental work.

For use in patent litigation alone, notebooks are imperative in modern research. Fortunately, they have additional values. Through his notes, an investigator may follow the progress of his own work, not forgetting for long bright ideas he has had, seeing new approaches to his problem, seeing new problems for study.

A social value lies in the possibility of having someone else continue the work if the original worker is not available.

4.00 Reject All Grounds for Relief Except Verification of Predictions

This attitude is an expression of *philosophical scepticism,* an unwillingness to accept statements which are not supported by evidence defined as verification of predictions. As a procedure, it is the negative aspect of the empiricism and pragmatism already expressed above.

This attitude is an expression of the view called *open mindedness* or *suspended judgment.* It is in opposition to the *will to believe in the absence of evidence,* to the psychological need for certainty. Rather than have a complete system of ideas unsupported by evidence, the scientific inquirer is content to have an incomplete system well supported. The acknowledgment of present ignorance is not resignation to defeat; it is rather that which leaves the way open for future investigation. It is a philosophy of caution, preventing the establishment of intellectual prejudice which would inhibit or interfere with scientific inquiry.

While accepting this view, the scientific inquirer recognizes that action must often be planned on incomplete information, the best available. However, he warns that such improvisations should not be given weight beyond the moment unless supported by later evidence.

4.10 There is no abstract principle by which the nature of things can be predicted before investigation of them.

The *classic rationalist* position is that we can know with certainty various general principles about the universe independently of observations; in fact, that observation is incompetent to provide them. Examples of such principles would be "every event has a cause" (cf. Section 2.21); "The whole is more than the sum of its parts" (cf. Section 1.20); and the chemical law of conservation of matter. The *rationalist* position that such general propositions are known *a priori* is opposed by the *empiricist* attitude stated above. (For a denial of specific *a priori* knowledge, see Section 1.11).

4.11 A statement may be significant without being true.

This attitude is in opposition to *hypothesis without verification.* An idea may be clear and understandable, without being true in the sense that some of its logical consequences have been verified. No hypothesis should be adopted until such verification has been accomplished.

4.12 Mere intensity of belief in a proposition is no guarantee of its truth.

"Intensity of belief" might be interpreted to mean the emotional strength of an individual's conviction. Such a psychological feeling of certainty has often been advanced in support of a belief in God. Yet, little weight can be attached to such evidence because the same feeling of certainty has been claimed by believers in witchcraft and by prophets of universal destruction at specified times now past. Peirce has demonstrated that the axiom, "A whole is greater than any of its parts," does not apply to quantities or collections that are infinite [5:210].

The term "intensity of belief" might also be taken to mean the number of persons accepting a belief. But it is easily conceivable that when a group has divided on a question the minority would be right. The decision should be based on evidence available rather than on a summation of intuitive certainty.

Conversely, intensity of disbelief or doubt, is no evidence of falsity. Many contributions to scientific theory have been unjustly refused recognition in the past because the advances broke away too drastically from the track of the scientific herd. Outstanding examples mentioned by Levy include work by Fourier, Heaviside, Waterston, and Mendel [33:199]. To this list could be added certain ideas of Galileo, Arrhenius, and others.

4.13 Lack of objection to a statement is no evidence of its truth.

The fallacy in arguing that a statement is true merely because it has not been, or cannot be, proved false is obvious. Accepting a statement without supporting evidence—simply because no objection to the statement is known—is called *belief in the absence of contradiction.*

If a statement can not be tested and possibly proved false, the statement is indifferent or meaningless, as pointed out in Section 5.00.

4.20 No authority can guarantee the validity of any conception.

Taken literally, this attitude is acceptable; not even the procedures of scientific inquiry can establish a hypothesis beyond doubt. However, distinction should be made between *expert authority* and *dogmatic authority.* An individual may use expert authority as a convenient substitute for his own verification; expert authority is derived from such verification. Dogmatic authority would not permit critical examination of the methods and principles by which its conception was derived.

An idea supported by dogmatic authority should not be rejected on that account alone. Rather, in scientific inquiry, the authority should merely be ignored and the idea tested just as ideas from all other sources are tested.

Objections to dogmatic authority are many. Some dogmatic authorities have been demonstrated to be wrong in the past. Once the idea of testing dogmatic pronouncements has crept in, then the bars are down. If any ideas are tested, why not all?

Likewise, dogmatic authorities have conflicted. There is no way by authority to resolve such conflicts.

4.21 The scientific inquirer should never make pontifical announcements, nor attempt to persuade by any means other than evidence adduced.

Mistaken ideas firmly held have often inhibited scientific inquiry. Scientific inquirers should not employ procedures likely to divert attention from the only means they will accept for testing the validity of hypotheses. Even when the inquirer feels sure of his hypothesis, he should permit it to be judged on its merits.

Logical argumentation and the presentation of evidence may not be the most immediately effective way of persuading those who differ from the scientist. But, in the long run it may be more desirable than propaganda which appeals to emotion rather than to reason.

4.22 No scientific inquirer should slough the responsibility of testing the validity of any conceptions he uses.

The scientific inquirer may choose not to test certain hypotheses when he feels them already to have been fairly well established. But, the responsibility for deciding is his. The individual should satisfy himself of the beliefs he accepts.

The inquirer is critical of his own beliefs. He should be equally critical of results offered by other workers.

4.23 Neither custom nor tradition can guarantee the validity of any conception.

Sometimes tradition is invoked as evidence for an idea. An analogy is drawn with the biological concept of *survival of the fittest;* the traditional idea has won out over competing ideas. However, many examples show that incorrect ideas may survive; some of them we call superstitions. Only the *good tradition* should be respected; what is good in the tradition can be determined only by testing the logical consequences of ideas.

As a means of fixing belief, immovable faith in an accepted idea is called the *method of tenacity.*

5.00 Reject All Untestable Solutions as Being Meaningless

The preceding attitude, to accept as evidence for the proposed solution only the verification of some of its logical consequences, is a specific criterion for the *intelligibility of theories.* If an idea is inapplicable in action, it is neither true nor false, but negligible, indifferent, irrelevant [2:56, 61], and a meaningless pretension to knowledge [41:129].

Untestable ideas are trivial scientifically even if belief in them affects human behavior. This identification of significance with verifiability has never occasioned much objection from non-scientists, because they have regarded it as a deficiency in scientific procedures rather than as a criticism of their own procedures.

5.10 The conception of an unknowable extra-empirical reality is rejected by the scientific inquirer.

Any fundamental distinction between *appearance and reality* is rejected. It is idle to ask whether scientific knowledge is "real" knowledge. All that the scientific inquirer asks is that it enable him to predict future experience successfully, that it be applicable logically.

Some scientists have asserted that the hope of discovering "an eternal substratum of possible experience in the complete world of events," a pre-existent "order of nature," is the motive for their work [2:144–145, 186]. But, the procedures they follow are indistinguishable from those of scientists who are simply seeking predictable sequences among events, verifiable consequences of hypotheses. Events often occur independently of the inquirer and sometimes against his wish. But things happen in a fairly stable way which can be studied.

Anthropomorphism and *animism* are explicitly rejected. There should be no ascription of human characteristics to anything not human, nor of conscious life to inanimate objects. Similarly, *supernaturalism* in general is barred.

5.20 A scientific law exists only when it is formulated by the scientist.

A scientific law has been defined as a well supported statement of relations among events. The formulation of it surely is influenced not only by the events but by the scientific inquirer—his background of ideas, his ingenuity, and the methods he uses. His ideal is achievement of judgments independent of his personal idiosyncrasies and of his culture, but he recognizes the impossibility of it. If his approach had been different his results might have been different.

Pearson points out that the view of scientific law as a transcription of a code

presented by some higher power probably arises from a confusion of scientific law with civil law. He says further that a scientific law is a description made by man; not a prescription by some higher power [39:112].

6.00 All Scientific Knowledge Is Only Provisional

There is no sharp distinction between *fact and hypothesis.* So-called facts have intellectual significance only when interpreted by a hypothesis or general principle.

The classification of scientific ideas is based on their relative probabilities. Facts are inferences from immediate sensory experiences; hypothesis, theory, and law represent increasing degrees of probability. Even our best attested laws—such as definite and multiple proportions, and conservation of matter and energy—are inexact, relative, and only probable. The scientific synthesis

> is a system of correlated ideas of similar derivation and various degrees of probability . . . approximate and mutable relations in a growing experience . . . [2:167, 185].

There is no idea so firmly established that it may not at some time need to be changed because of evidence brought against it. As Campbell has pointed out, scientific laws are not only the final product of scientific inquiry; they are its raw material [3:40]. Thus, conservation of mass has been reinterpreted in the light of Einstein's formulation of the relation between mass and energy. Atomic fission and contemporary studies of the structure of matter merely underline the necessity for such reformulation. There is no absolute knowledge; only tentative and provisional knowledge.

Intellectual conviction is a powerful prejudice. Appreciation of the provisional nature of scientific facts and laws should prevent such prejudice. In this connection even the word "true" is troublesome, because we are accustomed to think of a true statement as absolutely correct and incapable of improvement. It has been suggested that the word be eliminated from the scientific vocabulary, being replaced by the phrase "best evidenced."

6.10 No hypothesis or law, can be demonstrated; it can only be shown to be compatible with immediate sensory experiences.

Demonstration, or logical proof, depends upon assured starting ideas—first principles, premises, axioms, or postulates. In scientific inquiry, there is no assured starting point. Not even "facts" are necessarily true. Necessity exists only in formal science, which is independent of commonsense experience.

The test of a hypothesis has been said to be verification of its logical consequences. But even such verification does not establish the hypothesis beyond all doubt, for the same observed results might be deduced from, and be used to support, other hypotheses. The fallacy that such observed results demonstrate the hypothesis is called *affirming the consequent.* In critical experiments, the best we can hope for is that the results will be incompatible with the hypothesis—in which case the hypothesis must be discarded—or that they will be compatible—meaning that the hypothesis need not be discarded just yet. Actually the body of scientific knowledge and theory consists merely of the residue remaining after many unsatisfactory hypotheses have been eliminated.

The *argument from design* is a special case of the fallacy of affirming the consequent. It uses scientific laws, functional adaptations in organic structures, and the like as proof of a supreme intelligence directing natural events.

The mere probability of general principles resulting from induction has been pointed out in Section 2.11.

6.11 Any given event can be explained by more than one hypothesis.

Well known examples of alternative hypotheses include the wave and particle theories of light, and the conceptions of space as a continuum or as a multiplicity of points.

Another example has special reference to

science's rejection of an unknowable, extra-empirical reality (cf. Section 5.10). The compelling nature of events in shaping our ideas, even against our will, might be explained by a pre-existent order among phenomena; on the other hand, it might also be explained by an assumption that some supreme being causes us to have the same sensations.

When choices among alternatives are possible, they are made on the bases of adequacy and simplicity (cf. Section 6.13).

6.12 Not all possible hypotheses can be enumerated.

This attitude follows directly from the assumption that for any event there is a plurality of possible explanatory hypotheses (cf. Section 6.11), and from the assumption that there is no systematic way of deriving them (cf. Section 2.30).

6.13 Of the hypotheses compatible with the facts, the best hypothesis is that which is the simplest systematically.

To be acceptable at all, hypotheses must be true in that those of their logical consequences which have been tested have been verified. Once the adequacy of hypotheses has been established, then the choice is made on the basis of simplicity. There is a philosophical adage that hypotheses accounting for an event should be as few and simple as possible, should not be unnecessarily multiplied.

6.20 It is highly probable that there are phenomena capable of being observed but which have not yet been observed.

Probably things are happening right now without any one of us knowing about them. We believe natural radioactive processes have been going on for a long time, but people have known about them only since Becquerel and the Curies. Similarly, the electrical disturbances accompanying solar storms have been noticed only recently through their effects on wired and wireless communication systems. It is likely that, as our experience and our ideas are elaborated, we shall discover phenomena new to us but which have been occurring all the time.

It is obvious, too, that many logical consequences of accepted ideas have not yet been formulated and put to test.

Such ideas as these underline the provisional nature of all scientific knowledge. Novel experience may require readjustment of ideas till then well established. Attempted verification of an additional logical consequence of an accepted theory may yield results not in accord with the theory.

6.30 No matter what sequences among events have been more or less established, there is no assurance that such sequences are not changing or will not change.

Scientific laws are summaries of past experience and predictions for the future. But if sequences among events should be changing slowly, or should change abruptly, there would be nothing for the scientific inquirer to do but revise his hypotheses as rapidly as he became aware of their inconsistency with experience (cf. Section 7.00). It has been pointed out that it is self-contradictory to speak of nature as possibly lacking order, that a chance order of nature is not less "orderly" than an order of repeated sequence [41:163–164].

6.40 No one is able even to outline all possible future developments in science.

Novelty and new ideas enter scientific knowledge in various ways. One is by inspiration, intuition, or just plain guessing with regard to common-sense experience (cf. Section 2:30). Another is by observation of phenomena hitherto unknown, as experience and ideas are elaborated (cf. Section 6.20). A possible additional way is by changes in the pattern of events as suggested above.

However, it is not necessary to assume a discontinuity in experience to explain such novelty. It has been pointed out that no sequence of events recurs complete in every particular. The effect of a cause may involve conditions different in some respect

from those which gave rise to it. Among the new conditions, a new uniformity or pattern might be exhibited, thus offering a novel experience [41:232–233].

Any of these avenues is capable of admitting sufficient novelty to exceed whatever limits might be set for scientific inquiry.

7.00 Scientific Procedures Are Progressive and Self-Corrective

The method of scientific inquiry is progressive. It admits new ideas, as pointed out above. Also, it claims *no infallibility* but provides for correction as evidence makes correction desirable. Thus, it contrasts sharply with other so-called ways of knowing. *Authority,* and *intuition,* not only provide no corrective measures; they deny the need for correction; on the grounds that they are infallible. They are conservative rather than progressive.

Scientific knowledge is not certain. Experience is being elaborated continually. There is no routine way of arriving at useful hypotheses. There is no way of demonstrating any hypotheses to be true. But at least hypotheses demonstrated to be false are progressively eliminated. The flow is in the right direction; of the ideas considered, some of the unsatisfactory ones are discarded.

7.10 In so far as two hypotheses are inconsistent, at least one of them will not be borne out by experience.

The first test made of any hypothesis ordinarily is for consistence with ideas already accepted. The test is based possibly on two ideas: first, one condition for intelligible use of language is that we do not contradict our own statements (cf. Section 3.11); second, of two or more possible predictions regarding the same event, none or only one will be verifiable (cf. Section 3.12).

Inconsistency with accepted ideas is a trouble signal. But consistency of idea with idea is no positive evidence for either idea. It is conceivable that a system of beliefs should be perfectly consistent and yet that each of the beliefs should be false. Evidence for ideas is obtained only through verification of predictions deduced from them (cf. Section 3.00 above).

7.20 Whenever a hypothesis and its logical implications are not compatible with observations planned to test them, the hypothesis should be revised until it is compatible or should be rejected.

This principle completes the background for hypothesis and verification. Ideas are judged not on their origin merely, but on their value in predicting events. They are not considered unless they do permit predictions; they are revised or rejected if the predictions based on them are false.

The scientific inquirer rejects the belief that knowledge consists only of unchanging, absolutely certain ideas. He believes that no such idea has been discovered. His position is that if some of the logical consequences of a hypothesis "... are contrary to the facts observed, it cannot be true. For a true statement cannot have false implications ..." [41:70]. Hypotheses incompatible with observations are revised or rejected. Levy says that the backyards of science are littered with discarded principles, destroyed by a single fact [33: 10–11].

Under Section 3.21, it was stated that all relevant independent variables but one should be controlled. In a new problem, the relevance of any variable ordinarily cannot be predicted before some experience with the problem is had. When some variable which was thought to be irrelevant is shown to have an effect on the events being studied, then hypotheses must be revised to include the new variable and steps taken to control it also.

Anti-scientific critics disparage scientific knowledge, because science holds theories to be true and then displaces them with other theories. They say that really true theories would not be subject to change. They call this rejection and revision of theories the *bankruptcy of science.* The scientific inquirer places his trust however in no particular conclusions, but in his procedures.

This attitude is opposed to *faith in spite of evidence.* It is against *tenacity as a method of belief.* Failure to revise or reject beliefs inconsistent with evidence permits erroneous beliefs to become established. *Superstitions* are beliefs based on the idea of cause-and-effect; the only objection to them is that they are not well founded.

7.21 When his hypotheses and laws are shown to be inadequate, the scientist revises them to form closer and closer approximations rather than discards them to start completely anew.

Generally, common-sense conclusions remain useful even after they have been shown to be false. For example, we still speak of the sun as rising and setting even though we have discarded the idea that the sun moves around the earth. Also, we still use the law of conservation of matter although the interconvertibility of matter and energy has been accepted. The changes in our hypotheses often are of such character, closer and closer approximations.

7.22 Even a false hypothesis may lead to valuable results.

In general, any hypothesis at all is better than none. Since each hypothesis is put to test, a false hypothesis cannot lead the inquirer astray for very long. When he discovers that his observations are not those his theory would require, he has increased his knowledge. Edison is supposed to have rebuked a fellow-worker who was discouraged by thousands of negative tests on a certain problem, with the thought that they then knew just that many thousands of things that would not work.

Also, testing and eliminating the false hypothesis establishes some of the conditions favorable to the formulation of new hypotheses (cf. Section 2.30). Some of these may be verified.

7.30 The wise scientist will use the best means at his disposal to prevent, to discover, and to correct errors in his work.

There is no one who is not liable to make mistakes. Scientific inquiry accepts this assumption, in contrast to the methods of authority and intuition which claim infallibility. Scientific inquiry then provides means for correcting mistakes. If it did not admit fallibility, it would have no reason to provide safeguards.

The ultimate check on scientific work is verification of predictions (cf. Sections 3.00 and 7.20). Lack of consistence with previously accepted ideas is a good index to trouble needing rectification (cf. Section 7.10).

The scientific inquirer attempts to discover his own mistakes before opening his work to public criticism. He repeats his own thinking, calculating, and experimenting. He uses more than one approach to the same problem. He recruits colleagues to check his work, using the same and still other procedures.

Finally, he publishes for the use and criticism of all who are interested (cf. Section 7:40).

7.40 The scientific inquirer should publish his work.

There are at least two important reasons for publishing scientific work. One is that growth of scientific knowledge depends upon it. Each inquirer tries to stand upon the shoulders of his predecessors. Largely through reading, he learns what ideas have been tried, what accepted, and what discarded. His common-sense experience is conditioned by the thoughts of those who have gone before. He may correct and extend accepted ideas. Then his work should be published to become a part of the cultural heritage used by his successors. Thus, the search for adequate laws and hypotheses persists not only in one man but in generations of men.

A second reason is that only through publication may the full force of public criticism be directed against ideas. No one has a monopoly of good ideas. Even after a scientific inquirer has subjected his work to the best critical tests he can, some other person may find a flaw in it.

. . . the greatest opportunity of each scientific generation is the overturn of old authority by the discovery of new facts . . . scientific men are always before the bar of their peers, every one of whom may gain some distinction for himself by exposing or correcting them [2:25].

8.00 Scientific Inquiry Involves Values

Many instances of selection among alternatives have been noted already. Private experience was rejected in favor of public experience (cf. Section 1.13). Attempts to grasp the whole of experience were rejected in favor of analytical-symbolical procedures (cf. Sections 1.21 and 3.11). The selection of problems for study was shown to depend upon individual fancy (cf. Section 1.22.) Provisional and mutable knowledge was preferred to certain and unchangeable knowledge (cf. Section 6.00). Truth of a statement was defined as success in inquiry rather than as correspondence, coherence, or usefulness (cf. Section 3.00). Each such selection depends upon a value judgment.

Some additional ways in which scientific inquiry involves values are discussed below.

8.10 The scientific method of inquiry is applicable to anything that can be reasoned on.

This attitude is the faith of the scientific inquirer. He has rejected all other proposed methods of knowing. He intends to employ scientific inquiry in the consistent description of all experience. He has had greatest success to date in the physical sciences, but biology, psychology, sociology and other fields are being successfully attacked.

A corollary is that the scientific method of inquiry should not be barred from anything that can be reasoned on. Occasionally in the past, organized religion has exerted temporal power to restrain scientific inquiry. Today, research on atomic fission is controlled. Scientists strenuously oppose such restraint.

8.20 ". . . ultimately the direct influence of pure science on practical life is enormous . . ." [39:29].

The Value of Technology.—Pure science has been conceived as fundamental research into relations of events, without reference to particular technological problems. The scientific inquirer has even been said not to care whether the product of his inquiry was useful or not, but to seek only to satisfy his passionate curiosity.

This view is often rationalized by saying that such unchannelled investigation is the best way to find new useful knowledge. The most valuable ideas may be the completely new ideas stimulated by the process of satisfying curiosity. No one can tell beforehand what results will spring from an investigation (cf. Section 4.10).

Another point of view is that value is not absolute. Nothing is valuable in itself; it is valuable to some one and in some capacity [41:145]. Thus, the selection of problems for study depends not only upon the problems, but upon the interests of the scientific inquirer (cf. Section 1.22). Likewise, the use made of scientific knowledge has objective and subjective aspects. The scientist may find one aspect of his results valuable; for example, he might use knowledge of atomic fission in developing new engines for peacetime industry and transportation. But, the same atomic engines might be used to power war-plants, warships, and warplanes. Other aspects of atomic fission might be utilized in atomic bombs. Atomic fission has certain characteristics; knowledge of these makes various uses of it possible. The values of atomic fission lie in what these uses mean to various people.

Relation of Scientific Inquiry to Ethics.—Scientific inquiry may assume moral significance as well as technological significance. ". . . we cannot divorce an act or object from the consequences which ensue upon the commission of the act or the possession of the object so far as its value is concerned" [41:152]. An act or experience is said to be "moral in so far as it has a definite effect upon our relations to others,

our own development, or our intellectual creed" [41:269].

Many people have based moral distinctions on the immortality of the soul. According to the naturalistic view, the mind or soul has no existence independent from the body "and there is no immortality in the *literal* sense of life after death" [41:244]. ". . . the notion of personal immortality must be discarded, and pure ethics cannot be an ethics of otherworldliness in the literal sense" [41:200].

Similarly, some people have established moral standards on the basis of authority and particularly supernatural authority. The denial of any authority as sufficient grounds for belief and the denial of any supernatural existence knocks the props from under such moral standards [34]. But moral standards need not be so supported. Scientific morality is based on "reflective examination of the consequences of social arrangements and behaviors in the experience of actual flesh and blood human beings" [4].

Further, some people have held that the deterministic point of view relieves man of any responsibility for his own actions; that he is no longer a free agent, but has his actions defined by events that occurred long before he was born. However, determinism as presented above requires no such belief. Men are part of nature and are affected by their own desires and wishes—they interact with their environments.

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HARVEST OF THE SEA

WILLIAM GARDNER

IN THE battle for survival in peace, as in war, Scotland is going all out to encourage its industries old and new, and anything giving promise of dividends is being exploited to the full. One of the most interesting industries—although at present just emerging from the experimental stage—is that connected with the seaweed resources of the much indented west coast of Scotland and its outlying islands.

As is well-known, iodine used to be extracted from seaweed by burning—known as kelp burning—but science has now stepped in and shown that by burning seaweed much of its valuable contents is destroyed. Other and less wasteful methods have been brought into use with results that are little short of amazing.

For now, with even only one of its constituents—alginic acid—put on a commercial basis, seaweed has become the basis for the manufacture of light weight woolen fabrics, textiles, transparent paper, plastics, ice cream, custard powder and soup, the fining of beer, surgical soluble ligaments,

medical capsules, and dental powders.

Nor has the Government been slow to see the value of this new industry. It has provided funds for the scientific development of the industry which should eventually give steady employment in the sparsely populated Western Isles and Orkney.

The new Government-sponsored body, the Scottish Seaweed Research Association, Ltd., was started in June, 1944. It received $100,000 from the Government's Development Fund, and a similar sum from the trades concerned with seaweed research on a dollar for dollar basis, ending in June, 1946. That amount was not expended by the Association and results were so promising and the industry so small that the Treasury agreed to back the Association for a further period of five years. The financial provision for this latter period is to be about $72,000 per annum, and the Treasury expects, but does not demand, that the industry and private supporters will provide a further similar amount annually.

The chief scientific head of the Association is Dr. F. N. Woodword, whose makeshift headquarters were until recently in an old air-raid shelter in Edinburgh. His staff operates all round the West Coast of Scotland, the amount of seaweed on the East Coast being commercially negligible. The staff consists only of some dozen technical and some half-dozen non-technical men and women. About three-quarters of the scientific investigations are carried out in University and Government laboratories.

As on the west coast of America it is the brown seaweed that is here garnered and dried for the use of the scientists. It falls into two main categories, the littoral, which grows above low-water mark and is sometimes called sea-wrack (or the "tangle o' the Isles", mentioned in the well-known Scottish song), and the sub-littoral, which grows below the water mark.

Of the former there are five kinds and of the latter three kinds to be found round the Scottish coast, and a recent survey—the greatest of its kind ever attempted—showed that there is enough littoral seaweed to produce 8,000 tons of dried weed a year.

In the course of the survey aerial spotting was undertaken. In addition three lady botanists tramped almost every beach on the West Coast of Scotland. The survey also revealed a bumper crop of sub-littoral seaweed—estimated to give a million-ton development—in the Orkney Islands, where it grows in amazing profusion, and big enough for harvesting every three years. But the problem there is how best to get that harvest in. Unlike the Pacific weeds the Scottish varieties do not float when cut, and are not usually visible from the surface.

Wartime experiments with a sort of lawn-mower-cum-vacuum cleaner contrivance met with some success, but it was not economical. So the Association, together with the Service Departments and Universities, and industrial research teams are now going all out to develop improved surveying and harvesting methods. There are now 18 firms interested in the development of the seaweed industry.

Work done by the chemical division of the Association in Edinburgh has made it possible to predict the exact proportion of mineral and other constituents of the common brown seaweeds at any time of the year, and industrial and technical research into their potentialities is being made by University scientists in Edinburgh, Glasgow, Liverpool, Manchester and London, in collaboration with the Association's scientific staff.

So great is the demand in Britain for alginic acid that three factories are now operating in the West of Scotland and one in South Uist. But as is the case on the American Pacific Coast, the development of research into the seaweed business is furthest ahead as regards its use in animal feeding stuffs, and all that is harvested could easily be absorbed at present for that purpose alone.

At the Rowett Research Institute at Aberdeen and at Reading University scientists are trying to ascertain the effects of seaweed in cattle food. The seaweed is also much in demand as a fertilizer, being largely used in Ayrshire for potatoes and in Jersey for tomatoes.

But it is the wide range of potential uses to which alginic acid and other chemical constituents of seaweed can be put that is spurring on the scientists and pointing the way to an increasingly important Scottish industry. The Seaweed Research Association has purchased a large house and grounds at Inveresk, near Edinburgh, as permanent headquarters, housing engineering, botanical, and chemical staffs. With all its forces concentrated it can look forward to making even more rapid progress in the development of its research into the uses to which this war-born baby can be diverted in his peace-time manhood.

DEVELOPING SKILLS IN THE USE OF CURRENT MATERIALS: A PROBLEM IN TEACHER-EDUCATION

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SCIENCE and technology have made a tremendous impact upon modern life. The way we think and behave is influenced dramatically by such events as the discovery of anti-arthritic agents, the isolation of new vitamins, the production of radio-isotopes, or the penetration of the "sonic barrier" by aircraft. Each scientific or technical advance carries with it the bases for social progress and social maladjustment. These are of equal concern to the high school pupil preparing to take his place in society, and to the adult responsible for capitalizing on the advantages while combatting the evils of maladjustment. How does it work? What good is it? What does it mean to me, and to society? These are the obvious and yet fundamental questions which reveal that science education finds its real origin and meaning in the present and future problems of society.

To achieve more functional objectives, through study of current problems, science teachers turn naturally to the use of "current materials." This term should not be construed as limited to newspapers and magazines. The definition adopted by certain California teachers in their recent book reporting their experiences in using current materials is especially useful. These members of the California Council for the Improvement of Instruction (CCII) define current materials as "any and all procedures whereby the adult secures his knowledge of what is going on." [1] This is a broad and inclusive definition and one which is particularly appropriate to present-day teaching. If science teaching is to be kept on a functional plane, then it behooves science teachers to put "current materials" in the center of the curriculum rather than somewhere in the periphery.

These current materials may take a variety of forms. Perhaps they are articles from daily newspapers, articles and pictures from *Popular Science, Science Digest, Life, Time, Fortune,* or other well-read magazines; perhaps they are radio programs, television shows, guest speakers, or field trips. These are current materials suitable for functional learning purposes, because they deal with important issues and because they are also used by adults not in school. This is an important point, since every teacher has a responsibility for developing habits and understandings which will persist after school days are over.

It might be expected that teachers would turn naturally to the use of current materials. Such, however, is far from being

[1] Lucien B. Kinney and Katharine Dresden (Editors): *Better Learning Through Current Materials.* Stanford, Calif.: Stanford University Press, 1949. P. 1.

the case. The manifold details of locating the materials, incorporating them into classroom activities, and planning new activities to give full scope to their effectiveness comprise a problem comparable to that of using visual aids expertly. In both cases the attitudes leading to their use, as well as the tactical skills, *must be learned*. A well-organized program is required to prepare the teacher for efficient use of current materials. It cannot be left to chance. On the contrary, teachers in service need the help of colleges and universities that can provide comparable programs on the use of current materials in the classroom.

Experiences with such programs reveal the mutual advantages inherent in these two-way propositions, whereby institutions of higher learning are constantly kept aware of the actual practices used by teachers. This two-way communication may be made effective by seminars, workshops, conferences, "Exchange" type periodicals or newsletters, or by making it possible for high school science teachers to discuss their use of current materials before college classes. Another fine example of such mutual cooperation is the one cited above for teachers who were members of the California Council on the Improvement of Instruction. During a three-year period these teachers (who came from all parts of California) and certain staff members from the School of Education at Stanford University worked together in improving the use of current materials. The result was not only increased expertness among the participating teachers, but a broadening of the teacher-education program at Stanford, in a manner to be described.

Recognizing its responsibility, the School of Education at Stanford has provided within its professional program definite experiences to establish the requisite attitudes and skills in the proper use of current materials. Prospective science teachers obtain these experiences chiefly in four areas.

One of the first contacts with the teaching use of current materials comes in "The Core Course in the Principles and Methods of Secondary Education." The use of specific current materials in the learning process has been encouraged by a "Secondary Curriculum Materials Workshop"—planned and built by students of this Core Course. Within this room the students collect and organize vast amounts of current materials of the newspaper-magazine type, set up files listing resource personnel and appropriate field trips for certain teaching units, and put up representative bulletin board (display area) materials. This course does a great deal in establishing the desirable attitude toward the use of current materials by *all* high school teachers.

For each of the major teaching fields a second course is provided dealing with the materials and methods peculiar to the field. Prospective *science* teachers take a course which is called "Curriculum and Instruction in Science." Among other requirements in this course, it is arranged that each student will complete one "Resource Unit" for a selected topic or problem in a high school science course. This resource unit demands a rich use of current materials; in fact, one of the criteria used in appraising each student's work is the completeness and appropriateness of current materials listed or enclosed in the unit. These resource units tend to become rather bulky as students include pictures, clippings, charts, booklets, etc. Within this course, also, specific attention is given to the *techniques* of using such current materials.

In these two courses which precede student teaching, it may be said that the competence in using current materials has been carried to the theory and planning levels. It is in student teaching that these competences are carried to a real behavioral level. A definite attempt is made to assign student teachers to situations where they will be actually encouraged to use a variety of learning experiences, including a rich use of current materials. Thus, these science teachers are guided in the use of magazines, newspapers, radio-programs, guest speak-

ers, tours to places of scientific and technological interest—all of which fall within the functional definition of current materials since these represent " . . . procedures whereby an adult secures his knowledge of what is going on." The Stanford supervisor and the public high school supervising teacher, therefore, evaluate the student teacher as to his resourcefulness and his skills in actually using these current materials in his classes.

A fourth pre-service contact with the use of current materials comes at this same time. This is in a course called "Teaching in the Secondary School," which is a "problems" course accompanying student teaching. Within this course (which is kept to sections of not more than thirty student teachers), science teachers are joined by other subject majors. It is in these small sections that student teachers work on common problems encountered in this climax to their professional preparation. Experienced teachers from nearby public high schools are brought in to give their very practical solutions and their insight into professional matters. In the last three years it has been possible to draw upon the rich cooperation extended by some five or six members of the CCII, mentioned above. These teachers have been invaluable in sharing their experiences with the younger group. Their enthusiasm in using more functional learning experiences—as outlined in *Better Learning Through Current Materials*—almost always appears to be contagious. With concurrent encouragement from the Stanford teacher-education staff, the credential candidates prove to be reasonably well prepared in the use of functional, current materials.

The successes reached at Stanford University in developing a consciousness of the place of current materials in science teaching and in achieving real skills in their use by young, prospective teachers have led the staff to order "full speed ahead." This is a problem in teacher-education which was successfully attacked on the pre-service level because it was given a real priority in the professional program. Constructive follow-up and in-service programs seem destined to produce science teachers who will deal realistically with the dramatic problems of scientific and technological advances as these continue their impact upon the individual, the family, and the community. It is their job to prepare citizens who can cope with the problems science creates. Science teaching must always use current materials if it is to meet the real challenges facing schools today.

THE NEW AND THE OLD IN SCIENCE TEACHING

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There was a day when we taught our courses with serene confidence in their worth and with a feeling of assurance that the place of science teaching in the public schools was secure beyond the possibility of disruption. It had become quite clear that the prime mover of the modern world was science. Science and technology had created the possibility of endless progress toward more secure and abundant living. Furthermore, their advance created problems of great complexity and urgency in the lives of men and the affairs of nations. Inevitably we looked to science teaching to provide the younger generations with the knowledge and skills that would steadily close the gap between the promise that science held out to mankind and the actualities that obtained. Hopefully, we looked to science instruction to help equip young men and women to grapple successfully with modern problems. The classical Latin grammar schools and the emphasis on the humanities gave way before the strides of

the prodigious infant of science. "More science teaching for better living in the age of science!" "Learn to think through science!" "Share in the Aristotleian goal of knowing all there is to know about the universe and man!"

Magnificent aims! Divine intent! And we rather thought that we were achieving our purposes.

As a group, we still hold these goals. But our confidence and assurance have been rudely jostled and undermined in recent years. Strong pressures for modification of science courses have been exerted by administrators, educational policy groups, and—most significantly—by science teachers themselves. The criticisms are seldom leveled at our teaching, as teaching. The art of good teaching has been magnificently mastered by many science teachers all over the country from the earliest days of science teaching to the present. Rather, the criticisms are that we have been shooting at the wrong targets. Our stated objectives are generally commended. But the content and procedures we have generally used to achieve these objectives are under fire as being related only in the most tenuous sense to these very objectives.

THE NATURE OF THE PRESENT STATEMENT

It is desirable, therefore, that we examine what we have been doing and compare it with the newer programs that are supposedly designed to meet the criticisms and to better achieve the objectives we hold. By definition, most of us teach conventionally. The very fact that we are so familiar with what we have done may have made it difficult for us to be self-critical.

The teachers of the newer science programs are seldom reluctant to voice criticisms of the conventional programs. It will be interesting, and possibly instructive, for us to see our programs through their eyes.

The present statement summarizes the criticisms most commonly presented by teachers of the newer programs. It also briefs the major characteristics of the newer programs that appear to distinguish them from more conventional teaching.

It should be recognized, of course, that no single program can be designated either as "conventional" or "new." The terms are useful only for comparisons. The most hide-bound conservative will find some of his own techniques employed in what is here called "the new." The most starry-eyed radical will agree that he employs many of the procedures found in that which is here designated as conventional. The new differs from the conventional in the matter of emphasis. For clarity, the differences will appear greater in this paper than they commonly are in reality.

THE DEVELOPMENT OF SCIENTIFIC ATTITUDES AND CRITICAL ABILITIES

How do the teachers of the newer programs respond to our conventional attempts to develop scientific attitudes and methodological abilities in our students? Their viewpoints run somewhat as follows:

Criticisms of the Conventional Programs. The evidence, say our detractors, is far from convincing that conventional programs have often achieved this goal or even made notable progress toward it. Various writers have analyzed the situation and their viewpoints are remarkably consistent.

One of the more recent statements is that of Kruglak.[1] He states his essential thesis in the following:

> "If the scientific method were a known sequence of steps, then it would only be necessary to memorize them and grind out the solution to any problem whatsoever. With the same set of data the same conclusions would invariably be drawn. Every high-school science teacher will testify that the majority of pupils can recite the successive steps, which his textbook describes as *the scientific method,* without ability to carry out even the simplest independent investigation."

The conventional teacher has taught for the scientific method as if it had a big "S" and a big "M." Actually, it is difficult to define *the scientific method* except for pur-

[1] Kruglak, Haym. "The Scientific Method and Science Teaching." *School and Society.* March 19, 1949, Vol. 69, No. 1787.

poses of gross identification and discourse. True, we know many of its ingredients. But we have been utterly naive, say our critics, if we have felt that accounts of the scientific great and discussions of the method would result in increased critical power on the part of the student. Bridgman's famous definition of the scientific method is as sound as any in its reflection of the myriad things that go on in the activities of the scientist at work. He stated: "The scientific method, as far as it is a method, is nothing more than doing one's damnedest with one's mind, no holds barred." [2] The definition is obviously too gross to be of any worth except—as it was intended—as an antidote to the stereotyped and naive conceptions of scientific procedures of inquiry apparently held by many science teachers both in high school and college work. Such an antidote is needed, say the critics. These traditional conceptions have been notably ineffective in producing critical and incisive abilities even among those who prepare for scientific vocations—at least outside the narrow confines of their fields of expertness. Certainly they have failed among the great majority of our young people who would profit from experiences giving them increased power with which to tackle the problems of daily living.

If we are to be honest, say our critics, we must admit that the usual science teacher has given little critical thought to how to develop critical thinking abilities—or, for that matter, what, in any precise or useable sense, makes the difference between a critical minded person and one who is sloppy in his thought processes. He vaguely assumes that the science class and laboratory will get the job done.

The teachers of the newer programs ask us to examine what we have done in our classes and laboratories. We are facing the criticism that what we have done is grotesquely well-designed to develop concepts of *authoritarianism,* but is remarkably ill-designed to provide the slightest chances of developing critical mindedness in our students. Some of our critics have gone so far as to say that the typical science teacher has done more to thwart the development of critical thinking processes than any teacher of the school. An amazing indictment, surely!

Just what is our critics' argument? It runs as follows.

The conventional science teacher appears to feel somewhat honor-bound to cover the material of the text he is using. He feels somewhat guilt-stricken if the end of the semester is looming near and he has several units yet uncovered. Although it is obvious that the teacher cannot, at best, cover but an extremely small portion of the science he is teaching (in terms of the basic archives of that science) he none-the-less struggles valiantly to cover, at least, the majority of content found in the textbook he employs. This has typically provided a heavy emphasis upon the acquisition of scientific facts and principles rather than an emphasis upon increasing the power of students to obtain facts or to use them intelligently in making decisions. Our attempts to cover the many facts and principles of science have allowed little time for the exploration of variant and conflicting viewpoints among our students. We run roughshod over doubt and skepticism. These are essential ingredients of the scientific temper and should be nurtured and directed, not ignored or stamped out.

Secondly, say the teachers of the newer programs, we deal typically with the nicely cleaned effluents of former controversy. We seldom handle problems for which there simply aren't any presently known answer. We seldom even recapitulate the storms, controversies, and wrong answers that were, historically speaking, the experience grounds for the development of the scientific abilities of many men of science. The "problems" of our science teaching are text-book problems, neatly identified, developmentally straight-jacketed, and baldly answered under a single-track, forced draft series of

[2] Bridgman, P. W. *Yale Review.* Vol. 34, No. 450, 1945.

steps and progessions. These are as profitless as vehicles for the development of critical procedures of thinking as they are atypical of real-life problems.

Third, say our critics, the very nature of our subject matter (conceived, as we do, as a body of organized and *tested* knowledge) admits of little or no argument. The teacher of social science cannot assign readings on our present foreign policy and expect to teach a particular viewpoint as tested truth. Consequently he has the opportunity, at least, of assisting his students in increasing their power of identifying problems, structuring them, checking viewpoints for consonance with known facts, pulling out the red herrings, and checking personal biases. Not so with the science teacher when he deals exclusively with the body of factual material he calls science. E always equals IR and let there be no mistake about it. It is a principle to be learned. Actually, it requires no reasoning at all in the psychological sense. There are no decisions possible here; no false issues; no red herrings; no choices. In short, the learning of this principle, or that S equals $\frac{1}{2}$ at ^{2}, or that the ammonium radical has a valence of one, or of the Mendelian laws admits but little of the development of what we vaguely call the scientific method and attitude when taught as they commonly are!

Let us be frank, say the critics of the conventional program. The majority of the learning experiences we provide in our race over facts are best designated as memoritor and verbalistic learnings. We are not habituating young people in critical attack on problem situations, in inductive reasoning, nor are we guiding them toward a higher synthesis of critical abilities than they had when they came to us.

Nor can our laboratories be said to emphasize the development of scientific attitudes or critical abilities, according to our critics. We send a student to the laboratory to check, with inadequate instruments, for answers he knows in advance reside in the teacher's note book.

The student does not determine the coefficient of expansion of a piece of metal by recourse to nature. On the contrary. He goes to the laboratory to see how closely he can get nature to conform to what he knows, in advance, is the "right" answer that is somewhere in an answer book. The answer is, for the student, an arbitrary and authoritarian answer. Thus our laboratories are often places where students engage in the rather dubious game of checking as closely as they can against the (to them) arbitrary and unchallengeable authority of *Science*.

Our critics remind us that most of us who teach chemistry have sooner or later mixed the chemicals so that students could not achieve the results their laboratory manuals indicated they would achieve. The manual may, for example, indicate that the cook-book procedure recommended would result in a white precipitate or a violent ring. The substitution of chemicals by the teacher makes the supposed result impossible of achievement. Yet the majority of the class will report out the result that the manual adumbrates. Is this obvious intellectual dishonesty a reflection on the personal integrity of the student? Not if we are to believe our critics. We have taught him this as a necessary concomitant of our procedures.

The student has learned that his task is to follow a step one, step two procedure. If he does not get the expected result it is because his own inadequacies have not permitted him to achieve the "right" answer.

The science teacher has actually taught this intellectual dishonesty and a fine disregard for observable facts as surely and inevitably as if it were one of the chief objectives of his teaching. So say our critics.

This—we are told—is teaching authoritarianism with a vengeance. The teacher of the newer sort of science program admits to an impression that a good deal of conventional science teaching results in an implicit viewpoint on the part of the student that science is the "correct" dogma and that

the scientist is the high priest of the modern mystery called science. Let us admit once and for all, say our critics, that the conventional laboratories are really not laboratories at all. Our "experiments" are not experiments. They are visual education devices whereby young people may visualize phenomena and gain facility with the manipulation of certain materials and apparatus. There is no objection to such use. The objection is that we kid ourselves and delude our students as to the meaning of what goes on in the laboratory. The objection is, further, that such uses are not enough—that the laboratory should do more for the student. The laboratory can, and should, serve the objective of developing critical procedures of thinking and inquiry.

Basic Elements of the Newer Programs. In the newer programs the students assume a high degree of responsibility for planning the areas of content, the organization, and the procedures of the course. In more conventional programs the teachers and textbooks largely determine these things. In the newer programs the students are more nearly at the active center of the learning process than in conventional programs. The teacher assumes the role of counselor, stimulator, and resource person. Direct teaching is done, of course, but is less prominent than in conventional programs.

These differences are not accidental. They are planned to achieve what is doubtless the most fundamental objective of the newer programs: the development of self-direction, purposiveness, and power of independent attack on problems for each student. The analyst could use the term "scientific abilities" to identify these traits. The teachers of the newer programs more cautiously speak of "critical abilities." They attempt to provide experiences that will teach the student to handle his own problems without the benefit of a teacher or textbook beside him. The hope is to make the teacher and formal education increasingly dispensable.

The teachers of the newer programs would probably accept the following list of competencies and traits as spelling out what they have in mind when they speak of critical abilities.

1. The ability to locate and define problems in the matrix of confused patterns in which they are commonly found in "real-life" situations.
2. The ability to structure problems so that they may be analyzed and attacked by a logical sequence of steps.
3. The ability to secure relevant information from appropriate references and to distinguish between data that are valid and those that are invalid. This includes a recognition of the basis of authority in any field and the meaning of authority in science.
4. The development of a value system that is in consonance with major traditions of democracy and the Hebraio-Christian ethic. This implies an increasing internal consistency in the student's value system and an increasing tendency to interpret and weigh issues and facts in terms of this value-system.
5. An increasingly explicit understanding of science as a method of formal inquiry with a recognition both of its potential usefulness, and its limitations when applied to socio-economic affairs.
6. A recognition of the validity of group attack on problems as against individual attack and a recognition of the common requirements of freedom for the advance both of democracy and science.
7. An increased ability in the communication arts of reading with perception and understanding, of critical listening, of effective speaking, and of effective participation in group discussion.
8. A tendency to act in accord with available facts and within the value systems of democracy and science.

The discerning reader will detect that the usually stated elements of "the scientific method" are imbedded in the foregoing and that the list includes a good deal not commonly thought of as elements of that method besides.

What do these objectives mean in terms of procedure? What does a class typically do when the teacher has these objectives in mind? Each objective will be referred to in turn in answering these questions.

Objective 1 suggests that neat problems, pulled out of their context of real-life involvement will not suffice for the educational diet. Only in textbooks are problems neatly defined for the individual. In life, the individual faces issues and problems that are submerged in a matrix of irrelevancies and red herrings. This objective

suggests that a prime responsibility of the science teacher is to assist young people in looking more critically at situations as they are found in life, and to help them better to locate and define the specific problems that are found in such situations.

The teacher usually avoids presenting clean-cut problems to the class. Rather, he stimulates the students to awareness of meaningful problems situations and helps *them* to make the identification and clarification of the concrete problems involved. The problem situations chosen will, of course, depend upon the maturity and interest of the group. In fact, they typically will emerge *from* the group.

Objective 2 suggests group planning and deliberation. Commonly, the entire group plans the procedures to be followed in the attack on a problem and then shares responsibilities to small groups or individuals for investigation. At times, however, an individual student may have an interest not shared by the group at large. That student generally presents his interest or states his problem before the entire group. The group—or committees of the group—criticizes the structure of the problem and assists the individual student in refining it to the point where he understands clearly what things he must do in order to secure the data he needs to answer his problem or resolve the issue of his concern.

Objective 3 raises serious questions concerning the role of the textbook in the newer science programs. It must be recognized that the use of a single textbook with little or no attention given to other reference sources would prohibit the development of this objective. For the student who is never given the opportunity to compare judgments and opinions of different authors will not be able to develop critical reading abilities to any significant degree. Moreover, the teachers of the newer programs insist that the student who goes through an all-too-typical high school program as a rule using but a single reference in each course will emerge from high school no more able than when he began his high school work to use newspapers, periodicals, reference books, and technical bulletins when he needs information or wants to find various authoritative viewpoints on a subject or issue.

This does not mean that the teachers of the newer programs believe that textbooks are by nature bad, however. Some do. But most believe the question is one of use. In many of the newer programs no single textbook is used. Multiple sets of textbooks are available as are other reference materials. However, in many of the newer programs a single basic textbook is placed in the hands of each student just as in more conventional programs. This textbook serves as a basic orientation point for the class. To the textbook use is added a rich resource of library reference materials. The textbook serves as a lode star for the group as a group, and a reference point for learning expeditions into a wide variety of experiences and use of other reference materials. But the textbook does not dictate the coverage of the course.

The wide use of reference materials is held desirable, not only for the reasons stated and implied in the objective being considered but also for two basic psychological reasons. First, the level of reading ability varies tremendously in most classes. This year, in the University High School of the University of Illinois a "Freshman Problems Course" (which combines the former general science with experiences in school orientation and communication skills) enrolls students whose reading abilities range from fifth grade to college senior and whose IQs range from 82 to 186.

It is evident that a single reference, and a single speed of coverage would be stifling to the student of high reading ability and IQ and frustrating to the student of low reading ability and IQ. Both the student of low academic ability and the student of high academic ability would profit from consideration of certain problems that they both must face (in health, for example). Furthermore they would profit by consider-

ing these problems together in the larger group. But one can penetrate far more deeply and range more widely than can the other. If each is to gain optimum development of his potentiality for self-direction and understanding, a wide variety of reference materials must be made available.

Second, a single reference—usually logically rather than psychologically organized—may be interesting and understandable to one student but not to another of equal reading ability and intelligence. There is a real distinction between psychological organization and logical organization. Unfortunately, most science textbooks are gems of logical organization and represent little or no insight as to psychological organization.

Some of the newer textbooks are far better organized than the traditional ones in terms of student interest, readability, and "psychological logic." It must be emphasized, however, that the most gifted and insightful author cannot know or meet the varied local situations that the teacher faces, or provide an organization of content that will meet the particular psychological requirements of a particular student in a particular class. For this reason the authors of some of the newer and better textbooks provide a large amount of suggested activities, reading materials, and sources that encourage the student and the teacher to go beyond the text into the life of the community and into a variety of reference materials. Here we have the rather odd situation of a textbook itself weaning the student away from a pre-occupation with a single textbook.

A good example of this is a recent textbook in biology that has been widely used in the newer programs of biology. The book, and its accompanying workbook, include a major unit in the conservation of soils. Over half the answers to conservation questions raised in the workbook cannot be answered or keyed by the central authors for the answers depend upon what is found in the local community and in reference materials available only from local organizations or pertinent only to the local situation. Such textbooks are frankly designed for teachers who want to teach the newer sorts of science courses here being defined.

Objective 4 is a judgment that the science teacher in American democracy is a representative *both* of science and of democracy. He is responsible, as are all teachers, for helping young people develop clearer conceptions of what is good and what is bad. He is in addition responsible for helping his students come increasingly to understand that science, itself, while essentially amoral, represents a value system in many ways remarkably synonymous with the value system representative of American democratic traditions. For both are founded on the method of intelligence and freedom rather than on authoritarianism and coercion.

This objective suggests the importance of reflective thinking on a variety of controversial subjects where factual data pertinent to the natural sciences may be adduced, but where differing conclusions and judgments are common according to different valuative concepts. It is not sufficient to answer what happened?, why did it happen?, and under what conditions would it happen again? Such questions as should it have happened?, should it happen again?, and what should we do to secure its happening again or prevent its happening? are necessarily pertinent to the teacher's role according to those committed to the newer programs. These are valuative questions and they are always involved in individual choice and action. Thus critical thinking is impaired unless individuals are helped to understand the place of values in their choices and action. Democracy and science are weakened unless individuals are helped to understand and accept those values that are consistent with the fundamental traditions of democracy.

Objective 5 suggests that the student should recognize science as one of several historical and contemporary means of formal inquiry. The student's real understanding of science as a method will depend

upon the adequacy with which the other seven objectives are realized. For real understanding of a method is heavily dependent upon habituation in that method. Teachers of the newer programs tend to agree that the objectives here posited are attributes of the critical methods of naturalistic inquiry (including the value concept) that—in formal fields of science—we think of as the scientific method. Objective 5 goes further than habituation, however. It suggests the value of the student taking stock of formal procedures of investigation and explicitly distinguishing scientific inquiries from those of intuition, pure reason, revealed truth, philosophical and historical methodologies, artistic analysis and synthesis, and so forth.

In many of the newer programs this is done in part by a study of significant periods in the history of science. The student is brought to discover certain common patterns in the general procedures and methods employed by men of science. It is important to note that such a program will develop a myth and a distortion unless the student sees the operation of science in its interaction with the many social forces of a particular time and place. The work of Vesalius or Copernicus cannot properly or profitably be seen without the perspective provided by some understanding of the social forces operating in the sixteenth century.

Most of the teachers of the newer programs recognize the *naivete* of the conception of scientific method held by those who believe that we can find speedy answers to vexing social problems by rigorous application of the scientific method. They assist young people to recognize the difficulties of applying the methods of the physics laboratory to fields where uncontrollable variables make controlled investigation literally impossible. On the other hand the very fact that the newer programs so often lose the fine distinctions between the natural and social sciences (the dividing lines are inevitably lost or dimmed as real problems are attacked) is evidence of the interest of the teachers of these programs in helping young people to see that natural phenomena, including social phenomena, are amenable to scientific attack.

A dominant characteristic of the traditional classroom is that of competitiveness. The emphasis is on individual acquisition of information as evaluated by instruments permitting the placing of individual students in a rank order and on a distribution curve. A dominant characteristic of the newer programs is cooperativeness. Objective 6 implies this emphasis. The goal is the optimum development of each individual and the procedures are generally those of shared, and group, responsibilities. This is believed to be the best sort of habituation in the democratic process. Furthermore, it is believed to be a good exemplification of the scientific process in modern times. Each scientist has "stood upon the shoulders" of those who have worked before him. Moreover, no scientist really works alone. He may carry on his investigations privately, and usually does. But they are fully reported in terms of assumptions and procedural details, as well as conclusions. Thus any other investigator competent in the field can repeat the procedures to determine the validity of the conclusions reached. Conclusions, in science, are not acceptable until there has been considerable group verification.

In the newer programs the student experiences the validity of this group attack. His assumptions, facts, and experimental procedures are exposed to the critical view of the group. He finds that sounder answers from a coefficient of expansion experiment come from a group synthesis than are apt to come from his own single results.

All may share in the formation of assumptions and the collection of data as well as in the formation of tenable conclusions and generalizations. The individual students gains respect for group process and presumably may learn that an argument or issue is best resolved by exposition of the facts and group interpretation of facts rather than by the violence or

repeatedness with which a conclusion or point of view is posited.

The most common outlet for information, understanding, and attitudes in modern society is through the means of communication. The maintenance and strengthening of democracy, and the solving of individual and common problems, depend to a large degree upon the ability of the people at large to utilize the means of communication for their own understanding, for the persuasion of others, and for intelligent exercise of the ballot. Information and misinformation avalanche us through the press, movies, radio, and television. The intent behind the avalanche is variously to educate us, to persuade us, to delude us. It is to cause us to buy this product, vote this platform, do this thing.

A chief goal of the newer programs is stated in objective 7 of our list. There is no area of human experience that is not directly or indirectly affected by science. This objective proposes, therefore, that the student be assisted toward critical understanding of the written and spoken word and aided in developing his own ability to communicate his beliefs and viewpoints with cogency. Considerable time, in the newer programs, is taken by group discussions, panel discussions, library research, individual presentation, and in informal group analysis. The intimate relationship between language and thought is beyond dispute. Habituation in cogent written and oral expression is habituation in the process of thinking. Thus the science teacher who feels there is little profit in teaching science if the student does not make at least verbalistic use of it, feels impelled to provide considerable opportunity for each student to engage in such use under supervision.

Objective 8 need not be elaborated greatly. Presumably we teach in order that our learner's actions may be socially more desirable and individually more satisfying. Too seldom have we helped the student bridge the gap between knowledge and understanding on the one hand and action on the other. This gap has most commonly been noted in the area of health. What one knows about the requirements for health is little guarantee of what one will do. What one knows about the genetic and anthropological evidences of innate racial equality is no guarantee of what one will do on a racial issue.

Recall the old farmer who, when asked if he planned to attend a meeting on good farming practices, responded, "Heck no, I ain't farming now as good as I know how." Objective 8 implies the desirability of providing outlets for knowledge and attitudes so that young people will experience the satisfactions of successful action and will become habituated in taking action where such is both possible and desirable.

Action, for high school students, is often restricted by their youth and many other factors. Nonetheless, the teachers of the newer programs have typically discovered many avenues of action open to their students. Almost all of these are communication actions such as writing letters to the editor of the local newspaper or addressing a service club on a local problem. But there are other forms of action such as modified relations to individuals of other races and religions, the undertaking of surveys of health, housing adequacy, recreational potentialities, wiser purchasing techniques and habits, sounder use of equipment, and so forth. All of these are forms of actions. Teachers of newer programs do not leave these actions to chance. They assist young people in gaining increased skill *in* these and other forms of desirable action.

THE DEVELOPMENT OF FUNCTIONING UNDERSTANDINGS

Today's schools are properly charged with the responsibility of meeting the needs of all the youth that attend them. But the curriculums of our schools are under attack as being poorly adapted to meeting the needs of the majority of the youth of school age. The Regents' study in New York State, and the Maryland study, were prototypes of studies that have been made—and

continue to be made—in many states of the Union in an effort to discover how well the schools are meeting the needs of youth today.

The results of these studies are discouragingly consistent. They showed that the typical American high school today contributes chiefly to preparing a limited number of students to enter college (not, necessarily, to their success in college) and but little to understandings and skills that will help the individual toward personal happiness and security and toward competent citizenship.

Criticisms of the Conventional Programs. The fields of science instruction have not escaped this criticism. How do the teachers of the newer programs see the content of the conventional science courses?

They insist that any serious study of the content in a conventional high school chemistry or physics course leads, inevitably, to the conclusion that the largest amount of the students' time is taken up by considerations designed as a running start for college courses of the same general sort. Actually, say the critics, what little data are available suggest strongly that such courses are not even doing this particular job as well as are certain of the newer sorts of science courses.

The average science teacher will probably object to the foregoing. He will doubtless insist that physics and chemistry courses provide the student with an understanding of his physical environment that should equip him for far greater enjoyment of his life and for insights and skills that will enable him to live more competently, safely, and securely. He may be right. But the critics don't believe it. If these values do emerge, say the critics, it is incidental and largely accidental. For the content is certainly not selected on the criterion of meeting needs. It is an internally logical discipline of value only to the individual who will some day become a producer of science.

Stanley and his colleagues have given a cogent expression of the general criticism that the teachers of the newer programs have of the logically organized science subjects when they wrote: [3]

"The fact is that the 'organized subject-matter' of the sciences represents the end product of learning rather than the process by which learning takes place. It is true that in the hands of the mature scholar this 'subject matter' is an effective tool of further research. But that is precisely because he is a mature scholar; for the immature beginner it is, typically, a set of verbal formulae having little or no relation to his experience and interests.

"In the second place, it does not follow that the order and sequence appropriate to the problems of the research specialist is necessarily identical with the order and sequence appropriate to the citizen. The organizational pattern adopted by the research disciplines was designed for a definite and highly specialized purpose. The scholar's problem is primarily intellectual, the discovery and verification of further knowledge.

"The problems of the man and the citizen, on the other hand, are practical problems. As such they are primarily concerned, not with the discovery of knowledge, but with the making of decisions and the formulation of policy.

"The difference, therefore, is that between the organization of material appropriate to the development of a systematic body of theoretical knowledge and the organization of material appropriate to the application of knowledge to the control of some practical human enterprise.

"The advocates of a curriculum composed of elementary and condensed reproductions of the contents of the various research disciplines ignore these fundamental distinctions between the problems of the scholar and the problems of the man and the citizen. Consequently, they have confused general education with an additive summation of elementary courses selected from professional education programs in the various scholarly disciplines. And they have also confused verbal mastery of propositions embodying information with functional and meaningful knowledge."

Basic Elements of the Newer Programs. There is no set body of content that can be said to reflect the newer programs of science. In a way this is unfortunate because it is literally impossible to describe the content of one of the newer programs. What it is this semester may be considerably different, in its details, from what it will be next semester. The reason for this is that the teachers of the newer programs give priority to the eight competence objectives that have already been explored. For these objectives obviously prohibit a

[3] Stanley, W. O., et al. *Social Aspects of Education.* Stipes Publishing Co., 1948. Pp. 136–137.

teacher-dictated content and encourage flexibility and group concensus as to appropriate content.

It is a gross error to assume, however, that the newer programs are shapeless and without direction. This error is commonly made. Although the *details* of content cannot be stated, there are *major areas of human and societal need* that are almost always involved. It is the detailed content by which these areas are explored that varies.

Typically there are three criteria by which the selection of appropriate content is determined. The first criterion is the problems and needs of the students themselves. Space prohibits their cataloguing at this point. But anyone who has studied the many reports and investigations on the needs of youth is aware of the fact that there are a number of basic needs that students hold pretty much in common. The help that a particular student will require in meeting a need will be different from that required by another student, perhaps, but he will have categorical needs in common with others. The "Imperative Needs of Youth" posited by the NEA is one form in which these research data have been summarized for curriculum use.

The teacher of the newer program sees his responsibility as contributing from his field of expertness that which is of assistance to the students in meeting their needs.

Societal needs serve as another criterion for the selection of content in the newer science courses. For example, many teachers have undertaken to help young people gain a clearer understanding of our ability, scientifically and technically speaking, to provide for human want in production, health, conservation, and so forth. The goal is to provide understanding of the technically possible and the gap between this potentially possible and the present actuality in order that students may have a firmer basis in facts upon which to judge the many proposals being put to the American people to lessen these gaps.

There are many areas of social concern in which the science teacher of the newer programs assumes responsibility. Modern mass production, the inextricable web of peoples and nations in the modern world, naive, undemocratic, and anti-scientific conceptions of superiority of one racial group over another, the control of atomic energy and its directed development for the benefit of mankind, the larger questions of world unity and peace—these are typical of the areas considered in the newer sorts of science programs.

A third criterion are the values of democracy. There has been no time in American history when valuative education was more important than it is in these days of continuing crisis. With American traditions of freedom, of individual responsibility, of the method of intelligence as superior to coercion, and of the dignity of the individual under attack internationally and even in this country, this criterion for the selection of content and experiences becomes crucially important. The science teacher's responsibility for valuative education is held to be particularly significant for science, like democracy, withers under concepts of authoritarianism, conformity, and intellectual slavery. The newer programs in science provide experiences specifically designed to help young people gain increased understandings and appreciations of these values and their meaning when applied to social institutions and procedures locally, nationally, and internationally.

Admittedly this represents a rather different conception of the responsibility of the science teacher than that traditionally held. But the teachers of the newer programs will insist that no one else in the school is as well equipped as the science teacher to make certain significant contributions to the preparation of young people for satisfying living and effective citizenship. They insist that such programs are quite as definitely science as are the traditional programs. It is, however, a different emphasis, a different organization of much of the old content, and an addition of a fair amount of content from the

archives of science not typically found in the conventional science course.

This, then, is a thumb nail sketch of some basic elements of the newer programs and the typical criticisms of conventional programs that have brought them into being.

In conclusion it should be noted that the newer programs are often required of all students. The content and experiences are believed to be so directly relevant to the student's needs and the values and understandings required for good citizenship that all students are enrolled. Such "common learnings" experiences in science do not replace the more specialized courses in the biological and physical sciences. Courses in these latter areas are offered on an elective basis for students who are interested in the more formal treatment of an area of science, and for those who plan to use them for vocational purposes: i.e., for college preparation.

It is interesting to note that in many schools where the required course or courses in science are of the "common learnings" sort and reflect the general patterns described in the foregoing, the enrollment in physics, chemistry, and biology—even though purely elective—has gone up. Perhaps this reflects the achievement of one of the highest goals of a good teacher in any field: To leave the student, at the end of a course, more interested in the area than he was when he entered the course. If the newer programs have done nothing more than this—if they have inspired and stimulated the student to want to continue his work with the philosophy, methods, and body of tested data we call science—there is much to be learned from them.

BOOK REVIEWS

JOHNSON, PHILIP G. *The Teaching of Science in Public High Schools.* Bulletin 1950, No. 9. Washington: Superintendent of Documents, 1950. 48 p. $0.20.

This is one of the most timely and valuable bulletins that has appeared in the science education field. It gives some very pertinent information about the status of science teaching during the school year 1947–48. Offerings, enrollments and selected teaching conditions were analyzed. Thirty-one tables summarize the data.

The findings are based on 715 public high schools (3.15 per cent) of the 23,947 public high schools in existence during 1947–48. The selected schools were a random sampling in so far as school size was concerned. Somewhat more than 60 per cent of the pupils of the seventh and ninth grade were enrolled in general science during 1947–48. Enrollment in eighth-grade general science and biology was equivalent to 75 per cent. Less than half of the high schools offered chemistry and less than half offered physics. The combined enrollments in physics and chemistry was equivalent to about one-third of the pupils of the eleventh and twelfth grades. More than 50 per cent of the high school pupils were enrolled in the four commonly offered high school science courses. Per cent of pupils enrolled in general science was 18.32 per cent (18.27 per cent in 1922); biology 19.51 per cent (8.78 per cent in 1922, 6.90 per cent in 1915); chemistry 8.62 per cent (7.40 per cent in 1922, 10.10 per cent in 1890); physics 5.49 per cent (8.93 per cent in 1922, 22.21 per cent in 1890). Boys and girls are about equally distributed in the science courses except in chemistry where there is a small majority of boys, and in physics where there are three times as many boys as girls.

Part-time science teachers outnumbered the full-time science teachers and men constituted more than 59 per cent of all the science teachers. The average class size was smallest for physics (19) and largest for seventh-grade general science (30).

General science is usually offered in the seventh, eighth, and ninth grades, biology in the tenth grade, chemistry in the eleventh, and physics in the twelfth grade. Many schools alternate physics and chemistry and there is a trend for smaller high schools to offer physics rather than chemistry if the two are not alternated. Science classes usually meet five times a week.

The troublesome problems reported were most commonly related to physical facilities such as equipment, supplies, rooms, and school.

MALLINSON, GEORGE G. *Sponsoring the Science Club.* Graduate Division, Western Michigan College of Education, Kalamazoo, Michigan. 18 p. 10c each.

The purpose of this bulletin is to suggest objectives for clubs and procedures for guiding teachers and club members to meet these objectives. The bulletin is divided into two parts: Part I—the development of the Science Club, and Part II the program of the Science Club.

GRETA OPPE

Dull, Charles E., Brooks, William O., and Metcalfe, M. Clark. *Modern Chemistry.* New York: Henry Holt and Company, Inc., 1950. 564 p. $3.16.

This edition of *Modern Chemistry* is a complete revision of the successful textbook written by the late Charles E. Dull. The book is modern in every respect with respect to subject matter and is well organized into units which the student can handle. Nice summaries, questions, and things for students to do accompany the units and offer not only review but activities in the chemistry laboratory and classroom.

Greta Oppe

Hopkins, B. S., Smith, Herbert R., McGill, M. V. and Bradbury, G. M. *Chemistry and You.* Chicago: Lyons and Carnahan. 1949. 772 p.

Chemistry and You continues to be a personal study of chemistry in its applications of life for each student regardless of his life's work. It shows so clearly where the control of science rests. It is an outstanding text by a group of outstanding authors and by an outstanding publisher. It is completely revised with new pictures, new type, new sections, new testing and new material without sacrificing the emphasis in the earlier editions which has popularized the text; namely, emphasis on the broad generalizations and general principles which find application in modern life and extend our mental horizons.

Greta Oppe

Des Jardins, Russell T. *Vitalized Chemistry.* New York: College Entrance Book Company. 1950. 376 p. $0.75.

This copy of the newly revised *Vitalized Chemistry* in Graphicolor covers the essentials of chemistry, topic by topic, emphasizing the important principles, facts, tests, and vocabulary, making it an excellent day-by-day study guide or ready reference for periodic reviews.

Greta Oppe

Cibulka, Dr. A. *All This Could Happen Only to an Engineer.* Highlands, Texas: Dr. A. Cibulka, 1950. 237 p. $4.50.

Dr. Alois Cibulka, consulting engineer and member of many engineering societies here in the U. S., has written this interesting biography of himself and his family and their life in Europe before coming to Texas. In telling his story, he gives intimate glimpses of peoples and conditions in Europe and intersperses a philosophy throughout its pages. He arrived in America in 1921 and in less than three weeks was signed up as a designing engineer in Mexico. Dr. Cibulka came to Texas in 1925 to work for Standard Oil in Baytown. Classified as a draftsman, he started work for the Humble Oil and Refining Company's engineering office in Baytown and remained in the same department until 1941. His comments on the world crisis are blunt and revealing. In like manner his comments on engineering education reveal his attitude and his training. Politics, religion, business, and whatnot are attacked by a caustic and humorous pen.

Greta Oppe

Anonymous Summaries of Studies in Agricultural Education. Washington, D. C.: Federal Security Agency, Vocational Division. Agricultural Series No. 57. 1948. 120 p. $0.30.

This is an annotated bibliography of studies in agricultural education with cumulative classified subject index, supplement No. 2 to Vocational Div. Bull. No. 180 prepared by the Research Committee of the Agricultural Education Section, American Vocational Association.

Greta Oppe

Andrade, E. N. Da. C. *Isaac Newton.* New York: Chanticleer Press. 1950. 111 p. $1.75.

Professor Andrade, F.R.S., a scientist of international reputation, is now Director of the Royal Institute of England. In this book, which is a personal portrait of Sir Isaac Newton, he not only appraises the man but the time in which he lived and the position of science in 1665. "From time to time," writes Professor Andrade, "there arises a man whose work, whose viewpoint, changes the current of human thought so that all that comes after him bears evidence of his spirit."

Greta Oppe

Ehret, William F. *Smith's Introductory College Chemistry.* New York: Appleton-Century-Crofts, Inc. 1950. 511 p. $4.25.

This present volume is a thorough revision of *Smith's Introductory College Chemistry* by James Kendall, one of the most widely used college chemistry textbooks. One of the most significant innovations is the adoption of the nomenclature recommended by the International Union of Chemistry. One of the significant things about this fine text is its fine organization of subject matter and clear presentation of chemical facts and principles.

Greta Oppe

Lucas, Miriam Scott. *Elements of Human Physiology.* Philadelphia: Lea and Febiger. 1950. 357 p. $4.75.

This widely used physiology text is popular, perhaps, because the subject matter is presented from the viewpoints of students and teachers rather than specialists in physiology. It is a text for courses above the freshman college level. Subject matter is arranged in such a manner that a student can build on his general information and then upon his newly acquired information. Some new features of this new edition include an extensively rewritten chapter on blood, a revised chapter on respiration to include aviation physiology. A discussion for absorption is new for this edition. The illustrations are useful and attractive.

Greta Oppe

WEITZMAN, ELLIS, AND MCNAMARA, WALTER J. *Constructing Classroom Examinations.* Chicago: Science Research Associates, 1949. 153 p.

Teacher-made tests have played, and always will play, a unique role in instruction. They alone can be specifically and intimately adapted to the unique organization and content and to the detailed immediate objectives of particular courses of study. These objectives and this organization and content characteristically differ so markedly from teacher to teacher of the same subject that no test constructed for wide-scale use can possibly accomplish well such purposes as the day-by-day motivation of pupils or provide the detailed diagnostic information needed in instruction, or constitute a satisfactory basis for the assignment of marks.

The above opinion of the authors leads them to believe that classroom teachers need to develop competence in the construction of classroom tests and that they need to be kept fully informed about important advances in the art and techniques of objective test construction. *Constructing Classroom Examinations* has been written to meet this need. As a result the authors have made their book as practical and understandable as possible, with a minimum use of statistical checking.

DESMOND, THOMAS C. (Chairman). *Young at Any Age.* Newburgh, New York (94 Broadway): Thomas C. Desmond. 192 p. Free.

This is the 1950 report of the New York State Joint Legislative Committee on Problems of Aging. This is a significant report of value to many persons, as well as legislatures, outside of New York State. Much time and effort was involved in its preparation. The problems relating to old age are becoming increasingly important everywhere.

JONES, VERNON. *Character and Citizenship Education.* Washington, D. C.: National Education Association, or The Palmer Foundation, Box 621, Texarkana, Arkansas-Texas, 1950. 149 p. $1.00.

This is a syllabus for use in teacher training. It was written with the cooperation of a workshop conducted at Clark University under the sponsorship of the Palmer Foundation. The purpose of the syllabus is to assist in the developing and conducting of courses, workshops, or seminars in character and citizenship education in teachers colleges and universities and in training programs in school systems. It is designed to serve many of the functions of a textbook. There are eighteen units. Some units are: objectives of character and citizenship education, relation of home and associates to character and citizenship development, the teacher as a leader of youth influence of religion and church upon character and citizenship development, and influence of newspapers, books, motion pictures, radio, and television on citizenship development.

WHITEHEAD, THOMAS H. *A Laboratory Manual of Elementary Chemical Analysis.* Boston: Ginn and Company, 1950. 64 p. $1.25.

This is a loose-leaf laboratory manual based upon semimero procedures to accompany the autor's text, *The Theory of Elementary Chemical Analysis.*

HORKHEIMER, MARY FOLEY AND DIFFOR, JOHN W. *Educator's Guide to Free Films.* Randolph, Wisconsin: Educator's Progress Service, 1950. 392 p. $5.00.

This is the tenth edition of *Educator's Guide to Free Films.* This edition lists 1927 titles, 485 of which were not listed in the previous edition. All new titles are starred.

Titles listed under science include 46 in biology of which 6 are new; 85 in chemistry of which 10 are new; 147 in general science of which 17 are new. In addition many titles listed under applied arts, health education, conservation, consumer education, safety, and geography would be equally appropriate for use in science classes.

Here's a listing of free films to which every science teacher using films should have access.

HORKHEIMER, MARY FOLEY AND DIFFOR, JOHN W. *Educator's Guide to Free Slidefilms.* Randolph, Wisconsin: Educator's Progress Service, 1950. 128 p. $3.00.

This is the second annual edition of *Educator's Guide to Free Slidefilms.* There are 428 titles of which 283 are silent and 145 are sound. Additionally, three sets of free slides are listed.

Slides and slidefilms are receiving more recognition in the visual education phases of classroom teaching. The publishers are rendering a great service to teachers in making the above compilation of titles and sources available.

SCHRODINGER, ERWIN. *Space-Time Structure.* New York 10 (65 Madison Avenue): Cambridge University Press, 1950. 119 p. $2.75.

In this book Professor Schrodinger investigates the geometry of the Space-Time continuum underlying Einstein's General Theory of Relativity and describes some recent attempts to generalize it The book is recommended for the advanced college student in mathematics and physics.

SMITH, HENRY LESTER. *Character Education.* Texarkana, Ark.-Tex. (P. O. Box 621): The Palmer Foundation, 1950. 32 p. $0.50.

This is a survey of practices in the public schools of the United States. The booklet includes: Attitudes toward Character Education, Opinions on Methods in Character Education, Twenty Patterns of Character Education in Use in Public Schools, Inaugurating a Program of Character Education in the Public Schools, Illustrative Plans and Examples of Twenty Patterns. Few publications have said so much about character education in so small a space.

Halliday, David. *Introductory Nuclear Physics.* New York: John Wiley and Sons, Inc., 1950. 558 p. $6.50.

Professor Halliday expounds the philosophical aspects of nuclear physics besides integrating problems and modern facts. Older concepts are revised in the light of current thought. More than 40 per cent of the 228 illustrations are taken from literature after 1945. The book is designed as a textbook for a beginning graduate course or an advanced undergraduate course in nuclear physics.

Symposium. *Parents Responsibility in Character Development.* Texarkana, Ark.-Tex. (P. O. Box 621): The Palmer Foundation, 1949. 109 p. $0.50.

The material for this book developed at Washington State College, Pullman, Washington in the summer of 1949 was sponsored by the General Federation of Women's Clubs. Its major theme is that character grows out of all kinds of *Learning* a child experiences, especially that in relation to his parents. It is a very interestingly written book, much of it in conversational style. The major parts are as follows: *Expressing One's Self, Being Loved and Accepted, Undergoing Discipline as Learning, Making One's Own Decisions, Taking One's Own Consequences, Gaining Enrichment Through Growth,* and *A Backward Glance.*

Townsend, Hebrert. *Our Wonderful Earth.* Boston: Allyn and Bacon, 1950. 152 p.

This is the story of how the earth came to be the great round earth it is today. It is about of upper intermediate grade difficulty. It is an unusually attractive book with many illustrations, mostly in color. Altogether this is one of the most appealing elementary science books that the reviewer has seen in some time. The three parts of the book are: The Heavens Above, The Earth Beneath, and Life on Our Earth. Plants, Animals and People are discussed in the last section.

Black, Kathleen. *Manners for Moderns.* Boston: Allyn and Bacon. 117 p. $1.00.

This is a delightful book for boys and girls of 'teen age interested in etiquette, parties, dancing, dating. It would serve excellently as a text in "common-learning" or guidance courses and would be a worthy addition to the high school library.

Johnson, Roswell H., Randolph, Helen, and Pixley, Erma. *Looking Toward Marriage.* Boston: Allyn and Bacon. 99 p. $1.00.

This book would serve excellently in college courses on marriage and possibly more effectively in a "common core" learning or guidance class in high school where both boys and girls are interested in problems of meeting the opposite sex, dating, engagements, and even marriage. The approach and advice seem to be quite practical. This is a good book for the high school library.

Symposium. *Proceedings of the Eighty-Eighth Annual Meeting of the National Education Association Held at St. Louis, Missouri, July 3–7, 1950.* Washington: National Education Association, 1950. 443 p.

Volume 88 of the Proceedings includes the addresses before the representative assembly, the minutes of business meetings, department notes, annual reports, and association records and information. Tables and charts provide the following interesting information: Enrollment in elementary and secondary schools for 1950 total 27,722,500 with 24,700,748 in public schools and 3,021,752 in private schools. It is estimated that the future school enrollment in 1957–58 will be 34,104,000, of which 7,555,000 will be secondary. Secondary enrollment for 1959–60 is estimated at 8,122,000.

During 1948–49 the total number of persons preparing to teach was 31,600, with a forecasted need of 77,084 new teachers. The need for 1953–54 is estimated at 97,936. The total outlay for public schools in 1950 was estimated to be about $4,600,000,000, but actually only about $1,565,-158,217 in "1900 dollars."

In 1950 the expenditure per pupil in average daily attendance was $185 or $62.95 in "1900 dollars." In 1950 we spent 1.84 per cent of our national income for public schools as contrasted with 3.09 per cent in 1930.

LONG, HERTA R. *Alpha ray-Beta ray Emission Chart.* Chicago (1515 Sedgwick Street): W. M. Welch Manufacturing Company, 1950. Free.

This free chart in color illustrates alpha ray and beta ray emission in Thorium (4n) series, Neptunium (4n+1) series, Uranium (4n+2) series, and Actinium (4n+3) series.

MORGAN, ALFRED. *First Chemical Book for Boys and Girls.* New York: Charles Scribner's Sons, 1950. 179 p. $2.75.

Sixty-four experiments are described that boys and girls may do at home, with many of the common household supplies serving as the basic materials of the experiments. The experiments describe what to do, the things needed, and the expected results. Interesting discussion precedes or follows the experiment description. The book is well illustrated and should delight any boy or girl having chemistry as a hobby. Chemistry or science clubs will find this a most practical book as will the chemistry teacher who desires to supplement his class demonstrations. It is an excellent book for the high school science library.

BROWNLEE, RAYMOND B., FULLER, ROBERT T., WHITSIT, JESS E., HANCOCK, WILLIAM J., AND SOHON, MICHAEL D. *Elements of Chemistry.* Boston: Allyn and Bacon, 1950. 703 p. $3.00.

Through the years *Elements of Chemistry* has been the national leader in its field. For going on nearly half a century the high school chemistry text of the above authors' has been America's most widely used secondary text. As a matter of fact the reviewer began and ended his high school chemistry teaching using the predecessors of this book. This new edition is thoroughly in tune with the times. It begins with a brief story of atomic energy and makes that story its motivating theme, carrying it along to the final chapter which treats of nuclei and nuclear processes and of the peace time benefits of atomic science. A new chapter on *Chemistry in the Home* emphasizes the close correlation of chemistry with everyday life.

There are over 200 excellent photographs, nine full pages in color, and more than 150 diagrams of experiments and chemical devices that add much to both the attractiveness and teachability of the book.

There are self-testing exercises, thought questions and exercises, and summaries.

BARNARD, J. DARRELL AND EDWARDS, LON. *Basic Science.* New York: The Macmillan Company, 1951. 631 p.

Basic Science is a new textbook for a one-year course in general science. There are 31 chapters comprising the following thirteen units: 1. Science in Everyday Life, 2. Above and Below the Surface of the Earth, 3. The Universe, 4. Radiant Energy, 5. Electricity, 6. Heat, 7. Weather and Climate, 8. Health, 9. Living Things, 10. Conservation, 11. Work and Power, 12. Transportation and Communication, and 13. Materials of Construction. The content material seems to have been well-selected. The photographs and illustrations are unusually fine and serve both to interest the pupil in reading the content and to challenge his thinking. A number of the illustrations are in color. The literary style is most readable and technical terms have been kept to a minimum. The average ninth-grade student should have no particular reading difficulties. Far too often these days there are ninth grade pupils with about fifth grade or less reading ability. But there's not much that textbook writers writing for ninth-graders can do about that except to write interestingly, readably, and as non-technically as desirable. Sentence structure and phrasing are important. In all of these aspects the authors are to be commended for a good job.

In recent years there has been much attention given to the teaching of the scientific method through problem-solving. Much of this attention has been evident in the literature and the discussions, but relatively little of it has gotten over into the classroom teaching or into the textbook content. It is the latter failure that has resulted in so little teaching of scientific method. Professors Barnard and Edwards have done something about that in this text, possibly more than any other writers in the field of general science. Scientific method through problem-solving is constantly emphasized throughout the text. Experiments have been selected to emphasize this viewpoint. Maybe the average classroom teacher can now put into functional use some of the many verbal ideas so long discussed. Facts, principles, and generalizations are used as a basis for problem-solving.

Each unit has an overview, a series of problems, summaries, self-tests, review material, tests emphasizing problem-solving and the scientfic method, unit activities, and a short bibliography. Experiments have been so selected as to require use of scientific method.

The reviewer considers *Basic Science* as the best junior-senior high school science textbook that Macmillan has yet published (and in the past Macmillan has had many leaders in the secondary field). Both the authors and the publishers are to be commended on publishing such an outstanding book. Its wide and long-continued usage would seem to be well assured.

SPEARS, HAROLD. *The High School for Today.* New York: American Book Company, 1949. 380 p. $4.00.

This is a refreshing book because it has something worth saying and it says it in a most interesting way. It is as vivid and current as today's newspaper. The issues are sharp and clear, the style is crisp and inviting. It has five major sections: (1) The School and Its Promise, (2) The Curriculum and the Student, (3) The Teacher and

the School, (4) The School and Its Past, and (5) Resting the Case for the People.

The emergence of the high school as a people's institution is clearly traced from its humble origins in New England in 1635 to the present complexities of the Atomic Age. The historical approach is useful, in fact necessary, for evaluating the new and older concepts of curriculum, methodology, and teacher-pupil relationships. In the third chapter, "Purposes and Proposals", the author outlines succinctly the reports of nine major school commissions. He states significantly that, "The purposes of the American secondary school are not new; it is only the proposals for attaining those goals that keep shifting with the times." The treatment of these basic surveys in one chapter is of great use to the student of secondary education for it brings into sharp focus a large quantity of reference matter that would otherwise require much searching and analysis.

In Part 2, the relationship of the curriculum and the student is clarified by showing the interaction of each on the school and community. The concepts of general and vocational education are shown to be closely connected. The author states, "All courses that a school requires of all students must be justified as general education, as necessary preparation for the everyday life of all citizens"; and "Vocation is an essential part of every high school student's program"; and "Vocational education and general education must function side by side in the program of every high-school student, if the realities of life are respected in school planning and operation."

The core curriculum is suggested as a means for concretizing learning for realistic life preparation. The techniques of teaching are presented in their historical sequence of development. The reader can therefore better appreciate the relationships between "purposes, principles, and practices." The significance of guidance in the educational plan is pointed out clearly. The book is outstanding for the clarity with which it expresses relationships between fundamental educational ideas. For the neophyte it ties together isolated points, for the experienced teacher it extends the horizons of older concepts.

"The Teacher and the School" is the title of Part 3 and among its chapters are "The Public and their Schools," "The Teacher's Salary," and "Democratic Leadership." These titles can not possibly convey the up-to-the-minute quality of the discussion or the what-does-it-mean-to-me flavor. The chapter on salaries is the best presentation of this troublesome issue that this reviewer has ever seen. It would make an excellent springboard for discussion at a faculty meeting.

Dr. Spears, in his characteristically sparkling style, calls his chapter on supervision and administration "Democratic Leadership" and heads his first paragraph "Is There a Leader in the House?" His views of what supervision and administration should do for the pupil, the teacher, and the community are sound and progressive. The qualities of good leadership are stated in practical terms. The relationship of supervision to curriculum revision is outlined in a direct and realistic manner. Liberally sprinkled throughout the book are pithy headings and quotations that drive home important ideas, for example, "Good Supervision Means Good Relationships" or "As a system of selecting teachers is polished, so the system of supervision often becomes tarnished."

"The School and Its Past," the fourth part of this fine work, traces the historical development of the high school in chapters titled "Formative Years," "Growing Pains," "Great Expectations," "The Principal-Teacher," and "Supervision's Meager Beginnings." Dr. Spears' writing has the objectivity of a scholar and the indefinable charm of a natural story teller. He states, "In the life history of the American secondary school, a story of a three-hundred-years' program toward universal education, there stand out only five highly significant dates:

1635, the Boston Latin School
1751, Franklin's Public Academy in Philadelphia
1821, the English Classical, or High, School
1874, the Kalamazoo Case
1918, the Cardinal Principles of Secondary Education . . .

They are promising dates, for in each without an exception, there is found the hope of better things to come for nation and for individual." From this point the narrative unfolds dramatically with lively characters (puritans, pioneers, homesteaders), atmosphere (the course of study of the Evansville High School, Indiana, 1863), pungent dialogue (from the N. E. A. proceedings in 1887), and suspense (how will the high school emerge in the end?).

The fifth and last part called "Resting the Case for the People" appraises the present and looks toward the future. It pulls no punches, as witness the following, "That too many of our young people are receiving an obsolete education, quite far removed from the lives they live outside the classroom and the experiences they are about to face, is an apparent fact." Yet, it closes on a warm note of hope, "Chief among the ingredients of the high school that has been sought for so long must be (1) the will of the people, (2) the enthusiasm of youth, and (3) the warm hearts of the teachers.

"The High School For Today" by Dr. Harold Spears is the product of a practical educator . . . a man who has taught, supervised, trained teachers, and who is now Assistant Superintendent of the San Francisco Public Schools, California. As a result, the book is thoroughly realistic. Its plan and execution are most praiseworthy. Such clarity and interest are rarely found in books on education or in any field for that matter.

The cartoons of Dr. Spears (he draws well) titillate the spirit as well as the intellect. He proves, beyond a doubt, how potent humor can be

as a tool of learning. His charts and tables are models of what visual aids should be. All in all, Dr. Spears has made the problem of the modern high school as alive and challenging as the freckled teen-agers who shuffle through its halls.

WILLIAM B. REINER

FREEMAN, OTIS W. (Editor). *Geography of the Pacific*. New York: John Wiley and Sons, Inc. 1951. 573 p. $10.00.

Geography of the Pacific has thirteen contributors who cover every important geographical aspect. They are specialists in this area. Economic development, human relationships, political development, and current problems are considered. Emphasis is placed on important Trust Territories. Excellent maps, drawings, and photographs add much to tne descriptive material.

With the present tensions in the Pacific area, this book is most timely and important. A wealth of information has been compiled about the Pacific, much of it not hitherto available. "The Mediterranean is the ocean of the past, the Atlantic the ocean of the present, and the Pacific the ocean of the future," so said John Hay, Secretary of State, more than half a century ago.

YORK, G. MORELL, ROWE, JOHN L. AND COOPER, EDWARD L. *World Economic Geography*. Dallas: Southwestern Publishing Company, 1950. 693 p.

World Economic Geography is presented as a social science with a sociological and anthropological approach. There is an emphasis upon the world approach throughout. Interdependence is stressed. Special attention is given to the human approach.

This text also places emphasis upon geography as an important phase of general education.

Part I considers the world; Part II the United States; Part III other regions of commerce in the western hemisphere; Part IV Europe; and Part V Asia, Australia and Africa.

GARDNER, VICTOR R. *Basic Horticulture*. New York: The Macmillan Company, 1951. 465 p. $4.75.

Basic Horticulture is a college text that presents the student with the necessary fund of factual information about the many kinds of fruits, vegetables, and ornamental plants, and with their methods of culture. In addition the author hopes that the material is presented in such a way that the student will be challenged to think for himself. Altogether the textbook does seem to have real merit and would serve as an excellent reference for the high school biology teacher.

POLLARD, ERNEST C. AND DAVIDSON, WILLIAM L. *Applied Nuclear Physics*. New York: John Wiley and Sons, Inc. 1951. 352 p. $5.00.

This is a revised edition of a textbook first published in 1942. Much new material has been added and other parts brought up to date. Peace time uses and implications of atomic energy are almost exclusively emphasized and intentionally so.

It is an excellent treatment of nuclear energy but high school teachers would find it not too easy reading.

GARRELS, ROBERT M. *A Textbook of Geology*. New York, Harper and Brothers, 1951. 511 p. $5.00.

This seems to be an unusually well-written textbook in geology. The approach is analytical and developmental. Emphasis is placed upon the understanding of geological processes. Graphic methods of presenting concepts are used extensively. The illustrations are good. The author is professor of geology at Northwestern University.

VAN PRAAGH, G. *Physical Chemistry*. New York 10 (51 Madison Avenue): Cambridge University Press, 1951. 295 p. $2.75.

This textbook, by an English author, seems to cover all fundamental aspects of physical chemistry in a most adequate manner.

MILLARD, NELLIE D. AND KING, BARRY G. *Human Anatomy and Physiology*. Philadelphia: W. B. Saunders Company, 1951. 596 p.

This is the third edition of a text first published in 1941. New material has been added and some older content has been revised. There are 309 illustrations with 55 in color. These latter contribute much to the book's appeal.

OTTO, JAMES H. AND BLANC, SAM S. *Biology Investigations*. New York: Henry Holt and Company, 1949. 245 p.

This is a combined workbook and laboratory manual in high school biology. There are 75 basic investigations and 25 special laboratory investigations. The manual may be used with any textbook.

EVANS, WILLIAM LLOYD, GARRETT, BENJAMIN AND SISLER, HARVEY HALL. *Semimicro Qualitative Analysis*. Boston: Ginn and Company, 1951. 240 p. $3.00.

This is the fifth edition of a college laboratory manual in Chemistry first published in 1937.

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